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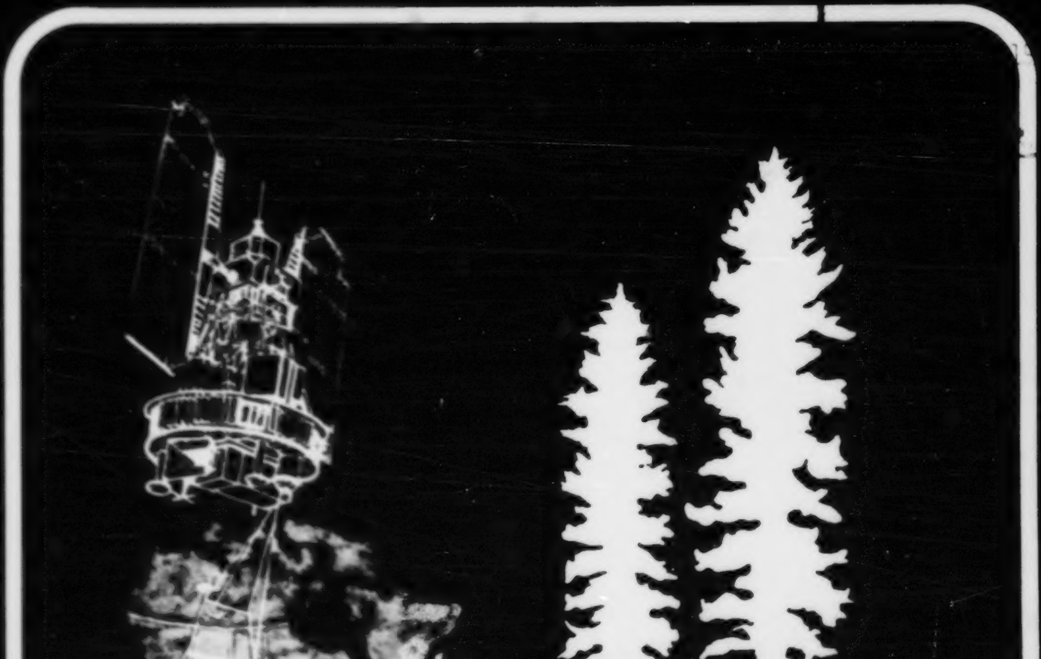
Practical applications of remote sensing to timber inventory

Proceedings of a workshop held September 26-28, 1979, in Edmonton, Alberta



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PRACTICAL APPLICATIONS OF REMOTE SENSING TO TIMBER INVENTORY

PROCEEDINGS OF A WORKSHOP HELD SEPTEMBER 26-28, 1979, IN EDMONTON, ALBERTA

COMPILED BY

C.L. KIRBY and R.J. HALL

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ABSTRACT

A workshop was held to review new remote sensing technology being applied to forestry by private, provincial, and federal agencies in Canada. Papers were presented on satellite image classification, large-scale photo sampling, sampling designs, computer applications in mapping and information systems, and the problems of technology transfer. In addition, a joint meeting was held by Canadian Institute of Forestry working groups for remote sensing, forest inventory, and biometrics, and two papers contributed at this session are included in the proceedings.

RESUME

Un atelier a eu lieu afin d'étudier la nouvelle technologie de télédétection à appliquer en foresterie par les organismes privés, provinciaux et fédéraux au Canada. Des documents ont été présentés sur la classification des images satellites, l'échantillonnage des photos à grande échelle, les plans d'échantillonnage, des applications mécanographiques en cartographie et dans les systèmes d'informatiques, puis des problèmes touchant le transfert de la technologie. De plus, une réunion conjointe a été tenue par des groupes de travail, de l'Institute canadien des forêts sur la télédétection, l'inventaire forestier et la biométrie; et deux contributions à cette session ont été insérées dans les comptes rendus.

PREFACE

This workshop was organized to provide a forum for the exchange of ideas and information with emphasis on the practical application of remote sensing to timber inventory for forest managers. There were four main objectives that it was hoped would be (and were) addressed by those presenting papers:

1. to present recent developments in forest timber inventory approaches;
2. to review the state of the art;
3. to illustrate how certain techniques should be applied to provide maximum benefit for the user; and
4. to identify research and development necessary to realize the full potential of recent developments in remote sensing and sampling techniques for intensive and extensive timber management.

Other members of the program committee who worked hard to make the workshop a success were:

C.V. Smyth, Faculty of Extension, University of Alberta, Edmonton

C. Bricker, Alberta Environment, Remote Sensing Center, Edmonton

Dr. J. Cihlar, Canada Centre for Remote Sensing, Ottawa

D.H. Fregren, Alberta Energy and Natural Resources, Edmonton

J. Lowe, Alberta Energy and Natural Resources, Edmonton.

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Northern Forest Research Centre; Environment Canada.

C.L. Kirby
R.J. Hall

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*Abstract only

WORKSHOP

PRACTICAL APPLICATIONS OF REMOTE SENSING TO TIMBER INVENTORY

Keynote Address: J. A. Brennan
Theme Address: K. A. Armson

NEED FOR FOREST INVENTORY

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About 3 years ago all the provinces and the federal government were asked to participate in a review of forest policies, which was a survey conducted by a task force of the CCREM. The resultant report, entitled "Forest Policies in Canada" (not to be confused with "Forestry Imperatives for Canada"), was three volumes, and unfortunately like most reports of this type it was accepted by all the provinces and the federal government and was filed for future reference. I have used that report more than most people, perhaps because I was directly involved in it.

One of the interesting aspects of the report was the responses to the questions each government jurisdiction was asked. CFS responded for the federal government, the Department of Indian and Northern Affairs responded for the Northwest Territories, and each province responded independently. On the subject of forest inventory, each jurisdiction was asked to state the objectives of forest inventory. Of the 12 responses, only one province and the federal government related the objectives of forest inventories to the social and economical benefits of people; even more surprisingly, only four jurisdictions (including the previous two) related the objectives of forest inventories to the planning and management of the forest resource. Eight responses appeared to imply the answer to the question was self-evident---the objective of forest inventory was to measure the forest resources, etc.

Therein lies a fundamental problem which should concern all senior government employees: highly technical and sophisticated programs can lose sight of the basic objective of providing a social and/or economic service to people. What makes this so critical to forestry is that the planning horizon is so far away that the beneficiaries, people, can be forgotten in a technical maze of problems. Remote sensing for forest inventory brings together three highly innovative and sophisticated technologies: satellite and high-level imagery, photogrammetry, and computer technology. Unless forest managers and field foresters become involved in the application of these technologies, there is a danger that the specialists will become overly concerned with technique and procedure and thus will lose sight of the basic objective of the program.

I hope that my comments will emphasize that there must be a need for the information generated, which must be generated in a way in which it can be used. Neither remote sensing or forest inventory or a forest plan is an end in itself. They are means to an end, and that end, I might suggest, is a managed forest which will provide a continuous supply of social and economic benefits to Canadians.

Our forest inventory has become more and more complex, not because of the deliberate effort of some scientists to confuse us with technical jargon (as some may feel I've implied in these comments) but because our information needs are changing rapidly. The forest manager, the senior bureaucrat, the company president, and the politician are demanding more accurate and speedy responses to their resource questions: How much should we cut? What if we change our utilization standards? What is the effect of Eastern Slopes policy on forest development policy, or recreation on timber harvesting? Can the Berland-Fox Creek timber support sawmills and pulp and paper mills, and in what combination? These are examples of some of the questions needing answers, and very often there are only hours or days to provide them.

A sophisticated management plan needs sophisticated inventory data. An intensive management program needs more intensive data. Critical resource management decisions require accurate data. Gone are the days when foresters can only be concerned with timber. Wildlife and cattle forage data, recreation and wilderness data, site and soil data, watershed and environmental data---all of this information and more is being expected and demanded from forest inventory, and we obviously can't be expected to generate this information from the old tally sheets we used 25 years ago.

One of the most important skills of a good forester is a thorough understanding and appreciation of the forest inventory he is expected to apply. As I previously inferred, this is becoming more and more difficult to achieve because of the complexity of the modern forest inventory. Many of the foresters of my generation spent years timber cruising. Not only were we involved in the fieldwork but we often had to see it to completion, to mapping and stand volume tables and perhaps even to laying out the harvesting operation. Today if the foresters in training are exposed at all to forest inventory, it is often to only a small element of the inventory system and more often than not with very little appreciation and understanding of the design, operation, and application of the inventory. Unless the organization makes a concentrated effort to overcome this problem, the end result is that the field forester is using an inventory in which he has little faith, and as he encounters errors in inventory, it only confirms his original belief that the inventory is too technical to be of practical value.

I don't suggest that we go back to the old strip cruise system to satisfy our total inventory requirements (I don't recall that statistical reliability, allowable error at a percent probability, was even part of our jargon then), but we have to expose our foresters to our forest inventory in such a manner that they can have confidence in the system.

In Alberta we were aware of this problem as the Phase III inventory was designed. One of the things we did was to involve field staff in ground truthing the photo interpretation results of the Edmonton staff. This technique of having the field staff check the photo interpretation for their area has worked extremely well and has given the staff a better understanding of the inventory system. This is not the total answer. Much more needs to be done in seminars and workshops to bridge the gap between specialists in forestry inventory and the forest manager in the field. In this regard, I am pleased to see that we have a good mixture of field and headquarters staff at this seminar.

Let me conclude my comments by expressing some concern about the sort of information needed and how it is used. As I mentioned information needs are more and more complex. Just knowing the volume of saw timber on a tract of land is no longer adequate. On the other hand the forest manager must recognize that the collection of enormous amounts of detailed data does not automatically solve his problems and very well may create bigger problems in data handling.

Flexible, cost-efficient, and timely techniques are required. Information, no matter how accurate and sophisticated, is useless if it can be provided only after the management decision has been made.

It is critical therefore, that forest managers insist on inventories providing information of the type, accuracy, and detail needed for management. It is equally critical that inventory and remote sensing specialists insist that the managers adequately define their information requirements.

In Alberta we are now producing our third phase of management inventory and are continuing to produce specialized inventories such as preoperational cruises. Each phase of inventory has been necessary because of changes in the forest and man's intensifying needs in management. Our present inventory is geared to what we consider to be management's needs for the next 10 years and to the funds and talents available to us. Continuity between inventories is important both for human reasons and because it takes years for one phase to replace the previous inventories in all areas. Our inventory has features which may not be applicable to other jurisdictions. With hindsight we know of improvements which could have been made.

There is one major need which Canadian inventories in general have not been able to satisfy in the past, and that is the need to summarize inventory maps and statistics quickly and conveniently. We have great volumes of detailed information of various ages but little ablility to summarize it effectively and efficiently. In my position I need up-to-date information summarized preferrably on one page or on one map sheet so that I can use it rapidly. I accept as an article of faith that modern technology can greatly assist the collection and storage of data. I therefore assume that similar technology can analyze and deliver the data in a manner that the user can digest.

Canadian forestry is in the forefront of the use of remote sensing for timber inventories. Meetings such as this are extremely important to keep the techniques and the needs in touch as they develop in our rapidly changing society.

TECHNOLOGY, FORESTS, AND FORESTERS

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Within the past few years there has been a renewed interest in forestry inventory and the related methodology. This is evidenced by the activity of the Canadian Forest Inventory Committee and other groups which have sponsored workshops such as that in 1975 on Canadian forest inventory methods (Smith and Aird 1975). As a forester I am not directly engaged in either the development of inventory techniques or their immediate application, yet I am still very much concerned with forest management, and I most likely have a perspective about forest inventory which is different from that of both the developer of techniques and the day-to-day user.

We often hear the blanket statement, "We need better inventories". Such statements really are begging the question. We should ask the simple question, "Why is it necessary to have a timber inventory?" While this may sound like both a simple and to many of you a naive question, I think it does bring us back to the matter of first principles. The question cannot be answered immediately unless we are given some qualifying information. Is the question being asked about a world, national, regional or provincial, company or management unit, working or operating plan area, or annual plan area inventory? Consider this question now in the light of the basic nature of an inventory, which is a statement about the quantity and/or the quality of forest trees (i.e., a detailed listing of arbitrarily chosen attributes). These attributes exist only at one instant in time and are finite spacially. Further, the list of attributes in itself has no intrinsic value.

The only value an inventory has is that which is given to it by the user or which exists in the eye of the beholder. Let me illustrate with two contrasting examples. At the operational level, a knowledge of the composition and the dimensions of the forests to be managed by harvesting or some other silvicultural treatment will more likely ensure that these activities will be undertaken effectively and economically each year. The value of the forest data can be expressed financially, and its accuracy and up-to-date nature is of crucial importance.

For my second example consider that a statement of Canada's forest extent at the national level provides, in addition to work for the compilers and considerable frustration, numbers that can be printed in papers and books that serve a multitude of purposes, most of which remain unknown or may only be surmized. These data may give a sense of pride to certain individuals who at international or other levels are asked for the forest statistics pertaining to the country as a whole. The data also may be cited by senior administrators, politicians, and others to demonstrate or to prove a particular point. In Canada, a national inventory has not provided or could not provide for planning and policy-making purposes at that level. The value at planning and policy making levels is being fulfilled in Canada only at the provincial level. I am not stating that there should not or cannot be a national forestry data base, but a call for an up-to-date national forest inventory is unnecessary for its development. I would emphasize the need for provincial inventory data that is compatible or translatable so that it can be aggregated for the country as a whole.

Let me return now to the initial question I posed, why do we need a timber inventory? For the operational and annual plan level I have already given the justification. When we consider the management unit or working circle level, the inventory is primarily of use in determining the annual allowable cut (AAC) and the extent and amount of the forest growing stock. It is these basic data and other information from the forest that enable forest management planning to proceed. The value again is one that can be expressed in definite financial terms, but over more than 1 year and usually 5 to 20 years. The relevancy of the inventory data is important, but a number of alternative procedures may be employed to keep it updated.

At the regional or provincial level the basic inventory is an aggregation of the information from management units. Its value lies exclusively in providing background data for both policies and rationales in the disposition and utilization of the forest and for its overall management. The level of accuracy and confidence limits are considerably different from those necessary in an operational or annual plan inventory. This provincial level is really analogous to that which in many other countries would be the national level of inventory use.

I would like now to consider the manner in which we go about doing our inventories. In Canada we often attempt either to make inventories serve purposes for which they are not intended (as, for example, when we use provincial inventories for operational purposes), or we expect that all inventories of a similar type should have the same data. It seems to me that Canadian foresters have never quite overcome their first flush of success from the 1940's in using black-and-white aerial photos and, allied to their use for forest type mapping, certain conventional ground sampling procedures.

The basic nature of many provincial inventories was set 20 or more years ago. From my own limited observations and more particularly the statements given in the 1975 workshop on Canadian forest inventory methods, I can perceive little evidence of innovation in the application of new techniques, many of which have developed using remote sensing.

This is not to suggest that new techniques have not been developed. Rather, there has been a limitation in the transfer of new technology to the applicator. The forest manager using an inventory technique he learned as a student, and a procedure that the organization he works for (usually a government or large company) regards as satisfactory, is loathe to push for the adoption of new procedures or techniques. There are, after all, vested interests against change in every organization. Furthermore, the innovators or developers of such techniques are suspect. They are often researchers and therefore impractical! Sometimes they become so enthused with their innovations that they ascribe qualities and applications to them which cannot be achieved, at least not in their first use. This readily creates a credibility gap between the forest manager and the innovator.

I will return to the matter of technology transfer later, but I would now like to speak on an item that both literally and figuratively is described by the term "point of view".

Most forest managers have their feet firmly on the ground. It is from this vantage point that they view their forests. Although they use aerial photographs to delineate stands, map cut-overs, and so on, they see this primarily as supplemental to ground observations or surveys. This has grave implications for those who are presenting remote sensing imagery as the prime data base that may have some form of complementary ground sampling as support---so-called ground truthing. I think it unfortunate that the term ground truth implies that ground sampling is more accurate than sampling done using remote sensing. I am sure many of us are aware that ground sampling may be equally as accurate or inaccurate as sampling using remote sensing.

This difference in point of view was brought home to me recently when, while setting up candidate Forest Management Agreement areas in Ontario, we undertook with local government and company foresters a survey of not satisfactorily regenerated (NSR) lands. The objective was to place these lands into five categories, and the procedure was to use a helicopter and visual imagery together with base maps. Any ground sampling was to complement the imagery, yet many foresters wanted to use the helicopter for "checking out the ground sampling" - a perverse approach to what we had intended.

I would add that these surveys also brought out the importance of recognizing the appropriateness of scale and cost. Foresters accustomed to earthbound procedures often look askance at what seem to be high-cost techniques such as the use of the helicopter at $300 per hour. Yet it is, to quote the businessman's current phrase, the bottom line which counts. If the high apparent cost translates into a low cost per unit area for surveys that may delineate lands where the forest manager would have spent many hundreds of dollars for silviculture treatments, then I think our cost of inventory is well spent. In the example I have quoted, a survey cost of about 75¢ per hectare may be compared with a possible treatment cost of $200 per hectare.

To return to the matter of research technology and the transfer of research findings, I cannot help but recall what an old friend and retired forester, Philip C. Wakeley, quotes as a research text. It is taken from McCaulay's poem "Horatius".

Now while the three were tightening
  Their harness on their backs
The counsel was the foremost man
  To take in hand an axe
And the Fathers mixed with Commons
  Seized hatchet bar and crow
And smote upon the planks above
  And loosed the props below.

Those who smote upon the planks made a great din and racket, but planks were laid to be smote upon, and it was the few who loosed the props who brought down the bridge and saved Rome from the Tuscans. Much research is plank-smiting; what is important are those endeavors which loose the props. But keep in mind that the idea of loosening the props to stop the Tuscans was of no benefit until carried out, when all could see its success.

There is a greater need than ever before for professionals and scientists to become committed to assisting the forest manager by bringing to him the applications of science. Dr. Gordon Baskerville has commented recently on the lack of these "go-betweens" in Canadian forestry. Much of what passes for applied research is mere plank-smiting. We delude ourselves and others if we call it research.

Those who are truly involved in research may quite properly be accused of not being practical and not making their research applicable to the manager, but I believe they should stand their ground firmly. The transfer of knowledge and technology is not their responsibility, and if they engage in it they may do both themselves and their discipline a disservice. I am not suggesting that research findings need not have any immediate practical application. They may well have application, but that should not be the raison d'etre of the research scientist. Similarly, the forest manager is a professional, and while he is a decision-maker, he cannot be expected to keep up with the scientific world. To return to my poetic analogy, he is often so deafened by the din of the plank-smiter that he does not hear the rasp of the saw or chop of the axe destroying the props beneath.

This meeting is attempting to bring together both the scientist and the manager, but I suspect that what is lacking is a strong contingent of the middle man---the go-betweens between the manager on one hand and the scientist on the other. These go-betweens in effect are catalysts who enter into the action and emerge, presumably unscathed, having fulfilled the objective of bringing two elements together.

There are occasions when a scientist can undertake his research right in front of the manager, and the studies can be highly relevant to the immediate problems of the manager. In my own experience, studies on nutrient uptake of nursery seedlings were undertaken in operational nurseries where the results could be and were interpreted and applied to the ongoing nursery soil management program. The go-between or catalyst was not needed. But this type of research and arrangement requires that the manager and the research worker jointly define the problem and collaborate in the study particularly in the interpretations of results and the application to the management problem. This type of arrangement, where there is no need for a go-between, is probably the exception rather than the rule.

You may ask what this has to do with forest inventories and remote sensing. It is this: with the rate of technical development in remote sensing and electronic processing of data, there is a great likelihood that practical applications will fall behind. It has become increasingly difficult for the manager to comprehend certain of the basic applications without becoming inundated in the technical jargon of the developer of whatever electronic gadgetry is being sold.

In addition, because of the rate of development of both hardware and software in this business, the manager who often works for the government or a large company is reluctant to purchase equipment that may be out of date, a result of the long time between placing an order and delivery.

Further, often the advantages of remote sensing in inventory have been misstated or oversold. For example, there are many situations in which remote sensing employing elaborate equipment and specialized interpretations was used to detect tree mortality that could have been detected by a forester knowledgeable of his area making routine aerial visual inspections, which may be documented by supplemental aerial photography.

To the present, applications of and new techniques for forest inventory have been of major benefit in assessments of remote areas, and this is as it should be. I believe that it is in the area of specific applications to managed forests that there is increasing need not so much for innovation but for the transfer of technology.

Considerable work has gone on in the use of large-scale imagery, yet with one or two exceptions it has not received the amount of emphasis or the application it deserves. In particular, I think that large-scale inventory has a very potent application in conjunction with ground procedures such as 3P sampling.

Another area of particular concern is the use of color infrared photography in the assessment of conifer regeneration. Basically, the technical features have been around for some time, yet its use to prestratify and assess regeneration is just developing.

The use of remote sensing to quantify and evaluate such practices as site preparation, precommercial thinning, fertilization, herbicide application, etc. are minimal, to my knowledge. Yet in these operations large amounts of money are being invested by the forest manager.

I can hear some of you saying, "We can do these things now; we don't need new technology." That may well be so, but remote sensing and even the interpretation of inventory is only one part of the picture. It is when that imagery or its interpretation is made an effective part of the overall documentation, inventory, and information system that a forest manager should have if he is going to be truly effective that we have the greatest benefit. It is this challenge that I think we should face today.

It is common to hear foresters plead that to improve and manage our forests effectively there should be more foresters in management or that the number of foresters per unit of forest area should be increased. There are those, citing European forestry, who would like to see a forester for every 10,000 to 50,000 hectares. Much as it may sound heretical, I would turn a deaf ear to this siren song.

The forests of Europe, most of which are 19th century or older in their origins, were established in relation to travel on foot or by horse, and all professional assessment and documentation was based on ground sampling. In Canada today, most of our access is by motor vehicle, and a forester's activities and much of our assessments are ground based. A management unit tends to be 100,000 to 500,000 hectares or greater. If the problem is that our forests are too large, we must realize that they are only too large if our foresters use 19th century procedures and early 20th century transportation to carry out their activities. The use of 20th century procedures, such as remote sensing, applied to present-day management activities for foresters using modern transportation can appreciably improve the effectiveness of our management and ensure that the highest professional skills and expertise are applied to our forest estate. It does not necessarily require that we have a large increase in the number of foresters per unit area of forest land managed.

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REMOTE SENSING TECHNIQUES: STATE OF THE ART

Chairman: C. Bricker

Contributors: R.V. Quenet
J. Cihlar, L.C. Goodfellow, and
R.G. Dixon
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METHODS OF ACQUIRING, INTERPRETING, AND PROCESSING LANDSAT DATA FOR USE IN FORESTRY

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ABSTRACT

LANDSAT imagery has placed a new tool, which can be used in forest classification, in the hands of foresters. It can be used as a supplement to aerial photography or in place of aerial photography where low resolution data are acceptable. The advent of LANDSAT imagery is most timely, as its incorporation into conventional forest inventories can do much to alleviate current deficiencies and improve future forest inventory statistics.

Satellite data and digital image analysis systems are described, practical applications of LANDSAT data are discussed, and selected examples of its use in forest management and inventories are presented. These include large area planning, updating existing inventories to reflect harvesting, forest fires, and new roads, reconnaissance inventories, forest inventory, forest fire management,

and detection of forest insect and disease damage.

As digital image analysis and satellite technology advances and their use becomes more widespread, we can expect significant improvements in and new applications of satellite data in forest inventory.

INTRODUCTION

The management of Canada's forest resource depends on the availability of current inventory statistics which are unbiased and appropriate for the required level of decision making. The magnitude of Canada's forests, an estimated land area of 3.14 million km^2 (1), results in very real problems in maintaining current inventory statistics. Recognizing the importance of the forest to the economy of Canada, our forest statistics are generally inadequate, and in many instances even elementary forest measures are not reported (2).

To improve our forestry statistics we must look at how forest inventory information is obtained. Forest inventory normally entails three procedures: 1. forest classification based on vertical air photographs at a variety of scales which are used to delineate forest types based on air and ground surveys; 2. forest sampling to obtain a) gross volume, b) decay, waste, and breakage factors to determine net volume, and c) growth and yield estimates for immature stands; and 3. compilation to merge forest type area information with sampling data to determine net volume per acre by species and mean annual increment for immature stands (3).

LANDSAT imagery has a proven potential in forest classification, and its incorporation into forest inventories can do much to alleviate current deficiencies and improve future inventory statistics. LANDSAT can be incorporated into forest management and operational inventories. It can be used as a supplement to aerial photography when photographs are available or in place of photography when it is not available or when the cost of obtaining new photography is not justifiable. The principal applications of LANDSAT data in operational forest management include broad area planning, detection of changes which may be mapped either directly or by dispatching aircraft to photograph the changes at high resolution, reconnaissance inventories, forest inventories, and for forest fire management and detection of insect and disease damage. The major advantage of LANDSAT data over vertical air photographs is its low cost, and except where adverse weather conditions dictate, it reflects the current state of the land surface. The LANDSAT satellites provide complete low-resolution coverage of Canada every 18 days; with both LANDSAT-2 and LANDSAT-3 operational, coverage is available twice every 18 days.

LANDSAT DATA

Resource-oriented satellite data first became widely available with the launching of LANDSAT-1 (formerly ERTS-1) by NASA (National Aeronautics and Space Administration) in July 1972. LANDSAT-2 followed in April 1975 and LANDSAT-3 in March 1978. LANDSAT-1 lost its integrity in late 1977 and was deactivated in January 1978.

The LANDSAT series of satellites are in a sun-synchronous, near polar orbit tracking north to south. The net effect of this orbit is to offset the flight path from true north. For example, flight path number 46, passing over western Alberta and eastern British Columbia, has a deviation of 16°E at latitude 50°N and a deviation of 20°E at latitude 60°N. This results in the need for geometric correction, which will be discussed later.

LANDSAT has two sensor systems: RBV (Return Beam Vidicon) cameras and MSS (Multi-Spectral Scanner) sensors (4); due to technical problems, however, only the MSS data is continuous. The MSS sensors record reflected radiance in four bands in the visible and near infrared regions. Band 4 (0.5-0.6 μm) approximates green light, band 5 (0.6-0.7 μm) approximates red light, bands 6 (0.7-0.8 μm) and 7 (0.8-1.0 μm) approximate reflected infrared light.

As the satellite passes overhead, it scans in a swath at right angles to its flight path. Each scan line has approximately 3200 picture elements or pixels. Pixel size is approximately 59 by 79 m. A LANDSAT image, approximately 185 by 185 km, has 2286 scan lines. There are six sensors for each band, and differences in sensor characteristics may be large enough to cause "striping". Radiometric correction can be used to remove striping.

In Canada, LANDSAT data are received and recorded at Prince Albert (Saskatchewan) and Shoe Cove (Newfoundland) satellite stations. All LANDSAT imagery that has been received to date has been placed in archives and is available through ISIS (Integrated Satellite Information Services Ltd.).

The products available include:

a) Photo products
   Black and white
      - paper prints
      - film transparencies*
   Color
      - contact prints
      - film transparencies*
   Mosaics
      - color and black-and-white prints
b) Computer compatible tapes (CCTs)
c) ISISFICHE

* No longer listed on order form.

SELECTION OF LANDSAT IMAGERY

The selection of good imagery is a major factor in the successful application of LANDSAT data. As previously mentioned, all imagery has been archived; therefore, the user may order imagery back to July 1972.

The procedure for selecting imagery is as follows:

1. Determine flight path(s) and image center(s) of required imagery from the LANDSAT Index map of Canada, produced by the Surveys and Mapping Branch, Department of Energy, Mines and Resources.

2. Use the IISS (LANDSAT Image Inventory Search and Summary Program) system or the LANDSAT imagery catalogues to select the best apparent images.

3. View the ISISFICHE to determine the location of cloud cover, presence of light cloud, and general quality of the image.

4. Select the image(s), paying particular attention to the date of the imagery. Imagery in northern and mountainous areas should be taken as close to the summer solstice as possible to minimize the amount of shadow. Since snow is often present in July, however, it may be desirable to select imagery taken later in the year. When

selecting images for change detection, it is extremely important to select images from as close to the same date as possible to eliminate different shadowing appearing as changes in vegetation cover.

Users would also be well advised to check CCTs very closely, as there are frequently problems with data.

GEOMETRIC CORRECTION OF LANDSAT IMAGERY

The easterly deviation of LANDSAT's orbits results in a problem in overlaying or incorporating satellite information with inventories based on NTS (Canadian National Topographic Series) maps. The CCRS DICS (Digital Image Correction System), based on PDP 11/70 minicomputers and a reprogramable geometric corrector, each day can produce about five high-quality corrected digital images, resampled, rotated, and framed to be compatible with NTS map sheets (5). Agencies anticipating the operational use of LANDSAT data should evaluate the advantages of geometric correction and should use geometrically corrected imagery.

ANALYSIS TECHNIQUES

Since LANDSAT data are available as paper prints, transparencies, mosaics, and CCTs, a number of analysis techniques can be used. These techniques include visual interpretation and mapping from black-and-white or color prints and mosaics, color additive viewing, and digital image analysis. Color additive viewing is not discussed in this paper because of the author's unfamiliarity with the procedure.

VISUAL INTERPRETATION OF PAPER PRINTS AND MOSAICS

Paper prints and mosaics can be used for broad-scale planning and for identifying major features such as forest, grassland, agricultural land, alpine, snow, water, logging, and burns. Multitemporal prints and mosaics can be used to identify new logging, burns, and other major disturbances.

This is a fast and inexpensive procedure that can provide current information; however, there are a number of serious limitations: 1. prints are not usually geometrically corrected: 2. data are difficult to transfer to maps; 3. the procedure is not suitable for classification of forest types, location of roads, or detection of insect and disease outbreaks; and 4. there is high loss of resolution as compared to digital data. Prints and mosaics are nevertheless a useful tool not to be overlooked.

DIGITAL IMAGE ANALYSIS TECHNIQUES

The analysis of digital LANDSAT data requires access to a digital image analysis system. Two alternatives are available: use of an existing facility or acquisition of a system or the necessary components. The application of digital image analysis on a provincial scale will require an in-house system; however, feasibility studies should be carried out on an existing facility.

Systems currently available for feasibility studies include: 1. CCRS CIAS system, Ottawa, Ontario; 2. NFI (National Forestry Institute) ARIES System, Ottawa, Ontario; 3. MDA (MacDonald, Dettwiler and Associates) System, Vancouver, B.C; and 4. OVAAC 8

System, Toronto, Ontario. There are a number of other operational systems in Canada; however, availability of these systems is, at this time, uncertain (6).

The cost of digital image analysis systems ranges from under $100,000 for small software-oriented systems to between $375,000 to $600,000 for hardware-oriented systems capable of large-scale operational applications.

Digital image analysis systems typically consist of: 1. a host computer, tape drive(s), disc(s), and alphanumeric terminal(s); 2. an image display system; 3. image analysis software; and 4. some system to provide the output product.

A number of accessories can be added to significantly increase the speed of processing, to geometrically correct image data, and to provide high-quality output products. These include specifically designed image array processors; general array processors; hardware geometric correctors; microcomputers in the image display system; multiple image display terminals; and binary theme printers, color image recorders, and line plotters. The principal Canadian suppliers of digital image analysis systems and image display systems are DIPIX, MDA, NORPAC, and OVAAC 8 (Appendix).

Image analysis systems normally support capabilities such as radiometric and spectral enhancement, geometric correction and supervised, maximum likelihood, and unsupervised spectral classification. The speed with which these operations are carried out depends on the speed of the host computer and the presence of image or general array processors.

Radiometric Enhancement:

Radiometric enhancement allows adjustment of the radiometric intensities of an image to increase the visual representation of the image. The radiometric values may be defined arbitrarily or as linear, exponential, logarithmic, square root, or squared functions. Principal component enhancement (7) maximizes the radiometric information displayed in three primary colors.

Spatial Enhancement:

Spatial enhancement allows use of various forms of image filtering to enhance boundaries and linear and other spatial features. This procedure may be used to define "pure" pixels or regions of homogeneity.

Geometric Correction:

Geometric correction can be used to overlay an image to match a map or to fit another image. Ground control points are selected, and the image is resampled and reconstructed to fit either a map or another image.

Supervised Classification:

Supervised classification allows the user to define training sites of known types. The statistics on training sites are computed, and areas with similar spectral statistics are classified as that type. This procedure may result in two or more types of overlapping.

Maximum Likelihood Classification:

Maximum likelihood classification takes the spectral statistics of supervised classification types and, based on these statistics, assigns overlapped areas to one or other of the classes.

Unsupervised Classification:

Unsupervised classification examines the scene statistics and, through a migrating means technique, identifies spectrally separable features. The number of types desired can be prespecified or computed. Types can be further combined or separated.

These capabilities provide the framework within which digital image analysis is performed. The selection of the classification method depends on the aim of the classification and the user's knowledge and experience. Agencies contemplating the use of this technology should exercise extreme care in the choice of image analysis systems to ensure that the system meets their particular requirements. The training of operators is critical to the success of the application. Classification results will be obtained regardless of the care or knowledge of the user. I strongly recommend that potential users of the system attend the training courses conducted by the Applications Division of Canada Centre for Remote Sensing (8). Its content is excellent and will provide users with a strong foundation in the use of the LANDSAT data and digital image analysis systems.

OPERATIONAL APPLICATIONS OF LANDSAT DATA IN FOREST INVENTORY

As previously stated, LANDSAT data can be used in place of or to supplement vertical air photography when its low resolution is not a constraint or is less important than having current information. Why then has it not been used more widely in operational forest inventory? The principal reasons are the lack of available image analysis systems, the newness and relative complexity of the technology, and the general inadequacy of output products. With the advent of numerous systems and training courses, the only constraint remaining is output products. I believe that LANDSAT data will beome an integral part of forest inventory as soon as the capability to produce geometrically correct scaled line maps or vector files, which can be incorporated directly into inventory maps, is generally available.

Despite these limitations there have been a number of successful applications in both Canada and the United States, and numerous potential applications have been demonstrated in small-scale, research-oriented studies.

Use of Paper Products and Mosaics:

Black-and-white and color LANDSAT prints have been used extensively by divisional and regional foresters to provide current information for overall planning and to delineate harvesting and burns where inventory maps are in the process of or awaiting revision. For example, in early 1979, the British Columbia Ministry of Forests, Inventory Division, in cooperation with the Pacific Forest Research Centre, Canadian Forestry Service, undertook the construction of a color LANDSAT mosaic of British Columbia using the most recent cloud-free imagery. The selection of imagery was done by the Inventory Division and the Pacific Forest Research Centre; CCRS produced the color contact prints (bands 4, 5, and 7); and NAPL (National Air Photo Library) constructed and photographed the mosaic. The mosaic was photographed by NTS sheets and by forest regions. The prints are available in both color and black-and-white and are accompanied by a list of the image centers and the date of imagery (9).

This simple and inexpensive procedure has provided regional foresters with otherwise extremely costly or unobtainable information on the current state of the forests. The response has been very good, with some 200 prints ordered since July. With the 1975 B.C. mosaic and the construction of future mosaics, it will be possible to rapidly assess the location and extent of activity and fires. While this information may exist in other forms, its collation is difficult and time-consuming. In the northern areas of Canada, the Yukon and Northwest Territories, this procedure may provide the only source of current information over large areas.

Change Detection:

The ability to detect and map changes in vegetation cover will probably be the most significant contribution of LANDSAT data to forest inventory. The procedures involved are simple and can be rapidly executed to provide much of the information required to update forest type boundaries. The steps involved in this procedure are as follows:

1. Two images taken at different times are registered by the selection and acquisition by pairs of GCPs (ground control points) representing the same locations on both images. Typically, 50 GPCs are required for full images. This procedure takes approximately 1 hour.
2. Transformation coefficients are calculated.
3. The image to be corrected is then resampled and rewritten using the transformation coefficients. It usually is necessary only to resample bands 5 and 7. This procedure takes 2 to 3 hours using a PDP11/70 and approximately 15 to 20 minutes using a hardware corrector.
4. Changes are then detected by radiometric enhancement, i.e., ratioing or differencing bands 5 and 7 of the two images. The resultant image will show the location and area of change.

This procedure will show both clear-cut and selective harvesting, fires, the location of most new roads, cleared rights-of-way, moderate to severe defoliation, catastrophic disturbance, and any other disturbance that significantly alters reflected radiation.

The information can be used directly, or it can be used to define areas where low-level photography is desired to more clearly define boundaries, to determine the nature of the disturbance, or in conjunction with ground sampling to determine such parameters as volume of windthrow, volume of residual trees, extent of pest damage, environmental impacts, and other factors.

Application of LANDSAT Data in Forest Classification:

A review of the literature indicates that attempts to classify forest types have met with varying degrees of success. A large number of factors affect reflected radiation and unless they are taken into account, problems will continue. These factors include slope and aspect; species composition, i.e., hardwood and softwood component; stand age and density; and atmospheric inference. In addition, the selection of training sites used in gathering statistics for both supervised and unsupervised classification is critical to successful classification.

Much can be done to eliminate these problems. Images should be stratified by terrain (aspect, slope, and elevation) and by major ecotypes. Only good images should be used. Training or sampling sites should be restricted to homogenous regions by applying a homogeneity filter and thresholding to eliminate nonhomogenous (or edge) areas. If these procedures are followed, most of the problems in classification will be overcome.

Reconnaissance Inventories:

Reconnaissance inventories are extensive exploratory forest inventories which are based on forest classification and do not generally provide estimates of volume or mean annual increment (10). LANDSAT data are probably the best sources for reconnaissance inventories in that they are inexpensive, current, and cover all of Canada on a broad scale.

The particular method employed to classify broad forest types depends on the amount of ground sampling data available. Where considerable ground sample data are available, supervised classification is probably the best methodology. Where little ground sample data are available, unsupervised classification is more appropriate.

The largest current Canadian operational application of LANDSAT data in reconnaissance inventory is being undertaken by the Pacific Forest Research Centre, Canadian Forestry Service, in cooperation with the Yukon Lands and Forest Service, the Department of Indian and Northern Affairs, and CCRS. The primary purpose of the inventory is to obtain information on the vegetation of the Yukon, including vegetation patterns and forest stratification. Supervised classification will be the primary method of analysis.

Forest Inventory:

Forest inventories, as opposed to reconnaissance inventories, are designed to determine such data as area, condition, timber, volume, and species for specific purposes such as planning, purchase, evaluation, management, or harvesting (10). In using LANDSAT data to define forest types for use in forest inventories, the classification of types and definition of their boundaries is critical, since the results will be used to determine net volume per acre. The degree of accuracy depends to a large extent on the amount of ground sample information, terrain, stratification of ecotypes, image quality, and selection of good training sites.

The largest application of LANDSAT data to forest inventory in the Pacific northwest was undertaken by the Department of Natural Resources, State of Washington (11). LANDSAT data were used in one segment of a multistage sampling plan to produce typical forest inventory information. As a result of the study, the authors found that LANDSAT data

1. are cost-effective on an operational basis,

2. provide a statistically valid base for photo and ground sampling,

3. are more sensitive to spectral differences in cover type and yield more detail than a photo interpreter working on large-scale (1:12 000) photos (I feel this claim may be somewhat over-optimistic, although the authors

do indicate that photo interpreters can determine tree characteristics which are obviously not identifiable on LANDSAT data),

4. require stratification by terrain, environmental, site quality, and cultural data and training on "pure" sites to improve accuracy of classification,

5. are immediately applicable in overall planning, forest fire control, and taxation (based on detection of harvesting and subsequent site management), and

6. make it possible to stratify forest resource populations effectively, thereby allowing improved survey design as well as the opportunity to minimize the need for costly direct measurement.

No large-scale operational test of LANDSAT data for forest inventory has been undertaken in Canada at this time. I believe that LANDSAT offers a real opportunity and should be evaluated by agencies responsible for the resource.

Fire Control Management:

The National Forestry Institute, formerly the Forest Fire Research Institute of the Canadian Forestry Service, has undertaken the development of a fire management decision-making system using LANDSAT as the primary data source (12). This system, developed under the leadership of Dr. P.H. Kourtz, has been one of the most successful applications of LANDSAT data in forest management.

LANDSAT data were used to construct forest fire fuel maps showing vegetation classes that exhibit similar fire behavior, major new disturbances such as clear-cuts, burned areas, insect- and disease-killed timber, roads, and water bodies. These types were displayed through a Taylor enhancement that resulted in a color print resembling color aerial photography. These maps are used to determine the speed and strength of initial attack based on the combustibility of fuel at or near the fire and, in the case of large fires, to determine suppression strategy.

Insect and Disease Damage:

The detection of insect and disease damage to forests is dependent on the attacked trees demonstrating a stressed condition. If LANDSAT data are to be useful, the exhibition of stress must be sufficient to alter reflected radiation to the point where a spectral signature of the damage can be acquired or where the damage can be detected using temporal classification.

Several studies have been undertaken using LANDSAT data in an attempt to discriminate between healthy and damaged stands, with varying degrees of success (12, 13, 14, and 15). In general, damage is identifiable where canopies have been denuded, provided that stand density is high, or where marked color changes in foliage occur, as in red belt damage.

Based on these studies, the application of LANDSAT data does not appear to be extremely promising; however, it is useful for broad-scale planning of pest surveys and, with higher resolution satellites, is likely to be more applicable for damage appraisal (16).

CONCLUSIONS

LANDSAT data have been

shown to be applicable in forest management and forest inventory and, without doubt, will be used extensively in the future. The success of individual applications will be determined by the user's knowledge and appropriate use of both the algorithms and the data. LANDSAT data are most applicable where large-scale, current, and low-resolution data are required. Users who attempt to use it as a replacement for low-level aerial photography or to obtain detailed inventory information will certainly fail. Used as a component in multistage sampling and as a method of updating change, it offers unparalleled opportunities, and with the advent of new high-resolution satellites its application will become even more attractive.

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APPENDIX

CANADIAN MANUFACTURERS SUPPLYING DIGITAL IMAGE ANALYSIS SYTEMS AND COMPONENTS

1. DIPIX SYSTEMS LTD.
1785 Woodward Drive
Ottawa, Ontario
K2C OP9

Phone: 613-224-5175

2. MacDONALD DETTWILER AND ASSOCIATES LTD.
10280 Shellbridge Road
Richmond, British Columbia
V6X 2Z9

Phone: 604-278-3411

3. OVAAC 8 INTERNATIONAL (CANADA) INC.
4800 Dufferin Street
Downsview, Ontario
M3H 5S9

Phone: 416-661-5088

4. NORPAC LTD.
Box 70
Pakenham, Ontario
KOA 2XO

Phone: 613-624-5507

COLOR INFRARED AERIAL PHOTOGRAPHY AND ITS USE IN FORESTRY

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ABSTRACT

This paper reviews the state of the art in applications of color infrared (CIR) aerial photography to problems in forest inventory and management. The CIR film characteristics, acquisition, and processing are briefly reviewed, and a list of Canadian air photo companies which acquire CIR photography is presented. Previous applications to timber inventory, fire burns mapping, and to forest damage assessment are reviewed with emphasis on the use of small-scale photography. The costs of CIR, normal color, and black-and-white photographs for a unit-area coverage are compared.

INTRODUCTION

Black-and-white (B&W) aerial photography has been used by foresters for a number of years. Its applications to forest stand and type classification, volume inventory, timberland appraisals, sale and exchange of timber, forest roads, soils, damage assessment, and other areas have been comprehensively reviewed in the Manual of Photographic Interpretation (Wilson 1960). Since 1960, the use of color aerial photography by foresters has increased for both experimentation and operations. The basic reason for interest in color aerial photographs is the greater amount of information displayed, which allows extraction of more forest data. This is especially desirable because of the steadily increasing cost of fieldwork.

Two basic types of color films have been used extensively in forestry projects. "Normal color" film is sensitive to the same light energy as the human eye and allows for close reproduction of the colors of the original scene. Color infrared (or "false color") film is sensitive to the infrared radiation, i.e., light beyond the sensitivity range of the eye, as well as to the green to red regions (but not blue) of the visible spectrum. Radiation in the infrared region is especially sensitive to the amount and condition of the living plant material. To reproduce the original scene in what has now become a conventional manner using color infrared (CIR) films, more care in storage, handling, exposure, and processing is needed than for normal color films.

COLOR INFRARED FILM CHARACTERISTICS

The CIR film most often used in North America is the Kodak Aerochrome Infrared Film 2443 with an ESTAR Base. The same film is also available with a thinner emulsion layer as Kodak No. 3443 (Fritz 1976). As in other color films, the emulsion consists of three layers sensitive to different wavelengths of light energy. The unique feature of CIR films is the presence of an infrared light-sensitive layer and a corresponding absence of a blue-sensitive layer (Figure 1). The remaining two layers are senstive to red and green light.

Since the infrared light (wavelengths greater than 700 nanometers) is invisible to the human eye, it must be reproduced in some other color. The universally accepted approach has been to show the infrared radiation as red, the red radiation as green, and the green radiation as blue on the processed film. Although each emulsion layer is primarily affected by one type of radiation (green, red, or infrared), it also has some sensitivity to the others. In addition, all three layers are sensitive to blue light (Figure 2), which must therefore be eliminated before it reaches the film. This is accomplished by using a sharp-cutoff Wratten Filter No. 12 (Figure 2) in front of the camera (Fritz 1977). The CIR film is a "reversal" film, meaning that the processed film is a positive transparency rather than a negative. The theory of color reproduction and reversal film processing has been discussed by Smith (1968), Fritz (1977), and other authors.

ACQUISITION AND PROCESSING OF CIR PHOTOGRAPHY

Color infrared photographs in various formats (23 cm X 23 cm, 70 mm, 35 mm) can be obtained using the Kodak 2443 film (Airborne Operations Section 1977, Reed 1979). While various camera lenses may be used for acquiring CIR photographs, some types such as those used on metric cameras are not optimized for this purpose. Wide-angle and superwide-angle camera lenses have been optimized for resolution and geometric accuracy at the expense of the lens speed and uniformity of film illumination. Thus, for a wide-angle lens, the illumination in the corners of the frame is about one-fifth that in the center (Fleming 1978). To counteract these variations, vignetting filters that are dense in the center and transparent at the perimeter may be used. Because these reduce the total amount of light available to expose the film and consequently limit the season and time of day when acceptable photography may be acquired, they are not normally recommended for CIR photographic missions. On the other hand, the considerably reduced number of frames required to cover a given area could offset the disadvantages of wide- and superwide-angle lenses for some projects.

Filters play a fundamental role in the acquisition of CIR photography. In addition to a "minus-blue" filter such as Wratten No. 12 (Figure 2), additional filters often are used to record the important scene information in an appropriate, distinctive manner. Since a large proportion (50% or more in some cases) of the infrared sunlight incident on plants is reflected, CIR film is constructed with the infrared emulsion layer being less sensitive than the other two (Figure 3). While this arrangement produces a satisfactory color balance or overall color appearance when a photograph is exposed from a low altitude, at high altitudes the amount of infrared radiation is reduced through atmospheric absorption while the green and red components are intensified by atmospheric scattering (Pease and Bowden 1969). Thus, for high altitude applications, the sensitivity of the red and green emulsion layers must be reduced in relation to the infrared layer so that the three curves in Figure 3 can be brought closer together. Such adjustment can be accomplished by placing appropriate filters before the camera (Pease and Bowden 1969, Fleming 1978), however, this reduces the effective speed of the film and increases the exposure length required. A preferable approach suggested by Fleming (1978) is to test each CIR film prior to the photographic mission, and reserve films with high infrared emulsion sensitivity for high altitude flights.

The sensitivity of the infrared emulsion layer also tends to decrease with time, particularly if the film is stored at temperatures above -18°C. To obtain the proper color balance even at low altitudes, the relative sensitivities of the three layers must again be brought closer together by using appropriate filters. Filters can also be used to deliberately shift the color balance of CIR photographs in order to emphasize particular features of interest (Fritz 1977).

Various sources of CIR aerial photography exist in Canada. All photography previously flown for or by federal government agencies is stored by the National Air Photo Library (NAPL). New photography is acquired by various provincial agencies as well as by the air photo industry. From Table 1, a recent list of companies that acquire CIR photography under contract, it is evident that CIR photographs at various scales can be acquired for all regions of Canada. Note that some companies listed are not registered with the Interagency Committee on Aerial Surveys.

The Kodak 2443 film in all formats is processed by NAPL, the minimum charge being equivalent to processing 25 ft. of film; 35-mm film can also be processed by Kodak. Continuous (roll) transparencies, individual frame transparencies, paper prints, and other products can be produced, although interpretation results from original transparencies are usually more reliable than those from duplicate transparencies, which in turn are preferable to results from paper prints (Murtha 1976).

CIR PHOTOGRAPHY INTERPRETATION

Except for its color dimensions, interpretation of CIR aerial photography is similar to that of B&W photos. Size, shape, texture, pattern, shadows, and surroundings provide important clues to the detection, identification, and description of objects observed in the scene. The use of color in presenting the photographed scene greatly expands the number of distinct shades that can be recognized by the human eye, however, and consequently increases the information content of the film. This is further enhanced by the film's sensitivity to the infrared light, although the use of red, green, and blue colors to represent infrared, red, and green light of the original scene introduces a color distortion which must be understood and accounted for by the interpreter. For example, the normally reddish bare soils will be displayed in shades of green; green vegetation, which is more reflective in the infrared than in the green, will appear red; while dead vegetation will be shown in gray or greenish tones, since the infrared reflectance is lower than that from living plants. The interpreter may also have to make allowance for a suboptimum color balance resulting from improper filtering.

APPLICATIONS

Although previous forestry projects involving CIR photography have been primarily experimental, several successful operational applications have also been undertaken. Inconsistent image quality caused by film variability and filtration have hampered the systematic use of this film in the past but can be eliminated now through procedures such as those described by Fleming (1978).

Some studies have shown that forest stands can be accurately delineated on small-scale CIR photos. For instance, Hegg (1978) delineated eight forest volume strata (three for hardwood, three for white spruce, two for black spruce) using CIR photographs at 1:110 000. Similarly, Carter et al. (1979) identified 12 vegetation categories (including five forested wetland classes) using both canopy and understory components from CIR photos of 1:130 000 and mapped them at 1:24 000. Dempster (1977) described an operational inventory of a 2 000 sq. mi. forest management area in Alberta using 1:50 000 CIR transparencies. For productive forest mapping units, the following stand variables were also interpreted from the small-scale images: density, height, composition (maximum of four species), origin, disturbance (if relevant), and steep slope (if relevant). As part of a spruce budworm mapping project in Nova Scotia, several forest stand characteristics were successfully mapped in only 2 weeks from 1:50 000 CIR photography over a large area (McAuley 1978), including species type (six categories), crown closure (five), height (five), land capability (five), topographic operability (two), and defoliation (four classes). At a scale of 1:160 000, Nielson and Wightman (1971) were able to identify major forest species associations in northern Ontario.

The usefulness of CIR photographs at various scales for identifying individual species has also been evaluated. Although some species identification and evaluation of a species proportion in a complex area is possible from small-scale photos (Beaubien 1975), relatively large scales (1:2 000) are required for a direct and consistently accurate identification of individual trees (Heller 1971, Myers 1974, Lauer 1968), because photo color must be supplemented by morphological information for individual species. For example, Heller (1971) identified 14 species with an accuracy of 95% from CIR photography at 1:1 600.

Small-scale CIR photography proved useful for mapping forest burns and regeneration (Bradshaw 1971, Gignac 1979). Gignac (1979) developed an operational methodology for mapping partial and total burns from 1:120-000 CIR photography at a scale of 1:20 000 using a stereo transferscope. Due to regeneration changes, older burns were also identified at this photographic scale. Adrich (1975) demonstrated the usefulness of small-scale (1:120 000) CIR photography for accurately identifying and mapping various forest disturbances such as harvesting, silvicultural treatments, land clearing, insect and disease damage, wildfire, flooding, and regeneration. He proposed that small-scale imagery should be used for a more frequent update of forest inventory data.

Over the years, there has been considerable interest in using CIR films for detecting tree stress before it becomes visually evident. This was thought possible because the infrared light is reflected by plant cell walls and at discontinuities between cell walls, water, and intercellular air spaces, and because the amount of reflected light depends on the amount and condition of these discontinuities. The ability of CIR films to "previsually" detect stress has not been conclusively demonstrated, however (Heller 1971, Murtha 1978). There is some evidence (Heller and Wear 1969, Harris 1971) that while the CIR film does not provide "previsual" stress detection, it does show stress more distinctly than does normal color film.

Various studies have been undertaken to determine the role of CIR film in forest damage assessment. Murtha (1974) demonstrated the usefulness of small-scale (1:160 000) CIR imagery for monitoring SO_2 damage. Beaubien (1975) and Beaubien and Simard (1979) used CIR spring imagery to accurately delineate several spruce budworm mortality classes (five classes at 1:60 000, three classes at 1:110-000). Each mortality class contained a certain proportion of dead trees (e.g. 0-5, 5-25, 25-50, 50-75, 75-100%); however, determining the extent of damage to live trees was fairly difficult. Results of work by Beaubien (1975, 1979) indicate that locating individual trees with 25-100% defoliation is not feasible on small-scale CIR imagery. At larger scales, normal color film can often provide more information on various types of insect damage than CIR film (Heller 1971, Bousfield 1973).

COST

Color aerial films are generally more expensive than B&W films. On the other hand, they also provide more information at identical scales or, equivalently, comparable information at smaller scales. For example, Dempster (1977) found that small-scale CIR photography permitted a reduction in line miles, flying time, interpretation time, and forest stand measurement costs because stand areas could be planimetered directly from the photographs with a reasonable accuracy. To assess the scale/cost trade-off, a formula was derived by computing the number of frames required to photograph an area of a given size at two different altitudes (and photo scales). Since for a given camera lens the coverage per frame is proportional to altitude squared, a relationship exists between the altitude (or photographic scale) and the cost of total coverage. Assuming that a more expensive film is flown at the higher altitude, the costs per unit area coverge (e.g., 1 km^2) will be equal if the scale factors and costs of the two films are related as follows:

$$\frac{\text{Scale Factor (higher altitude)}}{\text{Scale Factor (lower altitude)}} = \left[\frac{\text{Frame cost film Y (higher altitude)}}{\text{Frame cost film X (lower altitude)}}\right]^{\frac{1}{2}}$$

The total price per foot (film purchase + processing + continuous contact duplicating if applicable) of various film products as given by NAPL for 1979 was used in this formula.

Table 2 shows the results for five different films. It was assumed that negative films would be reproduced as prints and reversal films would be used as originals or duplicated as transparencies. Thus original CIR photography (film type 2443) at a scale of 1:16 000 would cost the same as B&W prints (2405) at 1:10 000. CIR photography flown at 1:18 000 would be cheaper, therefore, than B&W photos at 1:10-000. Given the high information content of color photographs at small scales, this trade-off appears attractive. If the CIR film is duplicated, its cost becomes equivalent at 1:20 000 (Table 2). The table also shows that it is cheaper to use original CIR transparencies than normal color prints at the same scale. It must be noted that total cost of a given flight mission includes items not considered here; therefore, the results in Table 2 will not be universally valid. Nevertheless, they show that the information content and ease of use of color films render them cost-effective when compared to B&W films.

SUMMARY

Color infrared aerial photography has been found to be a valuable tool for forestry applications. Advances in acquisition and processing have increased the quality, consistency, and suitability of CIR photos for forestry. Both experimental and operational projects have shown that such photography provides information on the types and conditions of forest stands. Since CIR small-scale photos contain more information than comparable B&W photographs taken at larger scales, th operational use of CIR can also be more cost-effective. For these reasons, CIR photography deserves serious consideration in current and future forest inventory and management operations.

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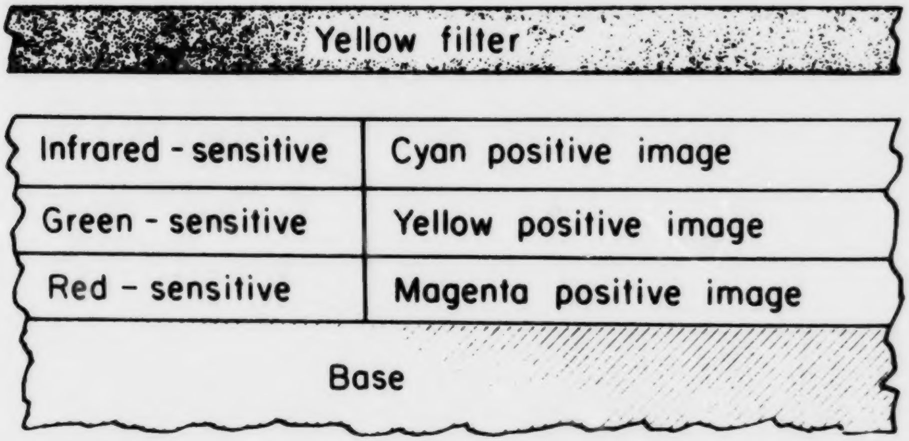
Yellow filter
Infrared - sensitive
Cyan positive image
Green - sensitive
Yellow positive image
Red - sensitive
Magenta positive image
Base

Figure 1. Composition of color infrared film.

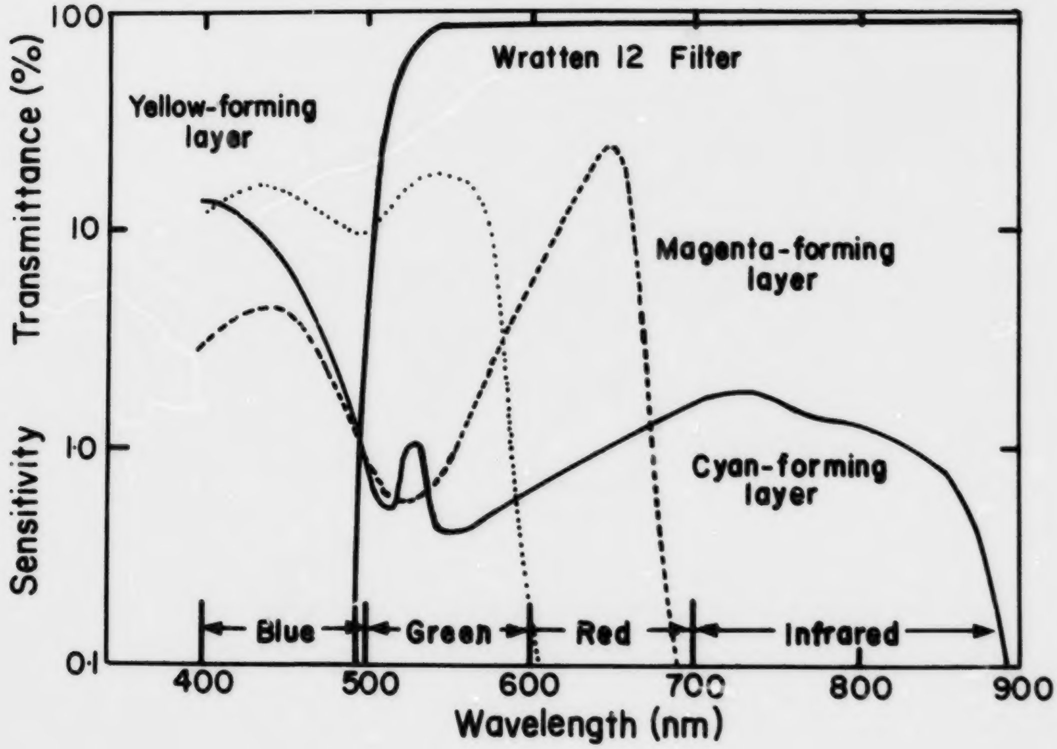

Figure 2. Sensitivity of color infrared film.

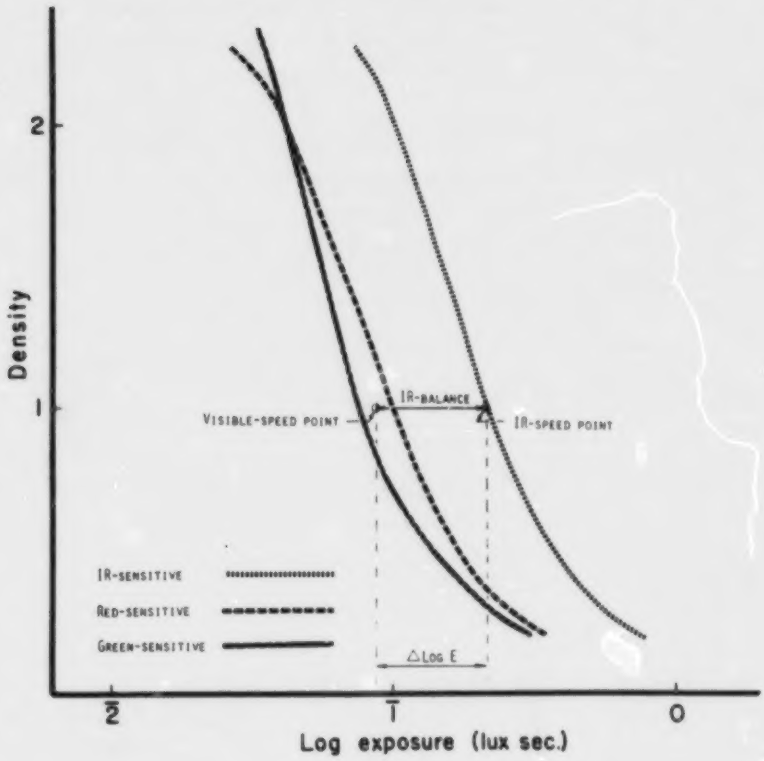

Figure 3. Relative densities of emulsion layers in color infrared film.

TABLE 1. SUMMARY OF AIR SURVEY COMPANIES ACTIVE IN REMOTE SENSING

Company	Sensors available	Lenses available	Film types available	Oblique vertical	1:50 000 photography on 9" X 9"	Lenses available for 1:50 000	Number of camera ports for 1:50 000	Active in
Aero Photo 1975 Quest Charest Ste-Foy Que. G1N 2E6	5-9X9 WILD Bendix thermal scanner	88 mm 152 mm	BW, NC+, NC-, CIR	Vertical	Yes	88 mm	2	East of Manitoba USA Overseas
Airquest Surveys Ltd. 1540 Gamble Winnipeg, Manitoba R3T 1N6	1-9X9 WILD RC8	152 mm	BW, NC+, NC-, CIR	Vertical	No (Yes in near future)			Saskatchewan, Man. N/W Ontario Office in Saskatoon, Saskatchewan
Atlantic Air Survey Ltd. (owned by Northway) P.O. Box 187 630 Windmill Dartmouth, N.S. B2Y 3Y3					See Northway Survey			

TABLE 1. (cont.) SUMMARY OF AIR SURVEY COMPANIES ACTIVE IN REMOTE SENSING

Company	Sensors available	Lenses available	Film types available	Oblique vertical	1:50 000 photography on 9" X 9"	Lenses available for 1:50 000	Number of camera ports for 1:50 000	Active in
Burnett Resource Surveys Ltd. 2973 Lake Cityway Burnaby, B.C. V5A 3A1	2-9X9 WILD RC8 1-70 mm Various 35 mm	152 mm	BW, NC+, NC-, CIR	Vertical	No			All of Canada Offices in Calgary, Alberta St. John's, Newfoundland
Also - Burnett - Whiffen Resource Surveys								
Capital Air Surveys Ltd. R.R. #6 Pembrooke, Ont. K8A 6W7	2-9X9 WILD 11-9X9 Zeiss Various 70 mm Vinten Thermal scanner	88,152 mm 305 mm 610 mm Various lenses for 70 mm	BW, NC+, NC-, CIR	Oblique, vertical	Yes Also 1:45 000 With	88 mm 152 mm 305 mm	2	Worldwide
GAR-X Air Survey Ltd. 1 Place Laval Suite 200 Laval, Quebec H7N 1A1	1-9X9 WILD	88,152 mm	BW, NC+, NC-, CIR	Vertical	Yes	88 mm		Worldwide

TABLE 1. (cont.) SUMMARY OF AIR SURVEY COMPANIES ACTIVE IN REMOTE SENSING

Company	Sensors available	Lenses available	Film types available	Oblique vertical	1:50 000 photography on 9" X 9"	Lenses available for 1:50 000	Number of camera ports for 1:50 000	Active in
Geographic Air Survey Ltd. 12851 - 148 St. Edmonton, Alberta T5L 2H9	1-9X9 WILD 70 mm Vinten	153 mm 12" 6" 3"	BW, NC+, NC-, CIR	Vertical	Yes Near future	88 mm		Western Canada, Yukon, Northwest Territories
Global Remote Sensing Inc. 650 Woodlawn Road West Unit 6B Guelph, Ont. M1H 1B6	2-9X9 WILD RC10	152,152 mm	BW, NC+, NC-, CIR	Oblique Vertical	No 1:30 000 or larger	152 mm		Worldwide
Integrated Resources Photography Ltd. P.O. Box 2278 310 Water St. Vancouver, B.C. V6B 3W5	1-9X9 WILD RC10 3-70 mm Vinten Various 35 mm - Thermal scanner purchase under negotiation	152 mm 3", 6", 12" Various	BW, NC+, NC-, CIR	Oblique 70 mm & 35 mm Vertical all	No			Canada west of Manitoba & Yukon

TABLE 1. (cont.) SUMMARY OF AIR SURVEY COMPANIES ACTIVE IN REMOTE SENSING

Company	Sensors available	Lenses available	Film types available	Oblique vertical	1:50 000 photography on 9" X 9"	Lenses available for 1:50 000	Number of camera ports for 1:50 000	Active in
Intertech Remote Sensing Ltd. 2841 Riverside Ottawa, Ont. K1V 8N4 Affiliates - Intera Environmental Consultants	1-70 mm Vinten 1-35 mm Olympus I-I^{2}S Multi-spectral camera 1-Daedalus Thermal scanner 2-closed circuit t.v. cameras	1.75 X 3" 150 mm	BW, NC+, NC-, CIR	Vertical	No			Worldwide, offices in Calgary, Alberta & Houston, Texas
Kenting Earth Sciences Ltd. 380 Hunt Club Ottawa, Ont. K1G 3N3	10-9X9 WILD 70 mm Vinten 35 mm	310 mm 85, 152 mm 50, 80 mm 28-50 mm	BW, NC+, NC-, CIR	Vertical	Yes	85, 152 mm	2 in DC3 A/C	Worldwide, offices in Calgary, Alberta, Kano and Lagos Nigeria
Norcor Engineering & Research P.O. Box 277 Yellowknife N.W.T. X0E 1H0	1-9X9 Fairchild 4-70 mm Hasselblad 1-35 mm -Low light level -t.v. digitizer for data aquist.	150 mm 40, 100, 150 mm 25-300 mm	BW, NC+, NC-, CIR	Oblique, vertical	Yes	150 mm		All of Canada especially Arctic, overseas

TABLE 1. (cont.) SUMMARY OF AIR SURVEY COMPANIES ACTIVE IN REMOTE SENSING

Company	Sensors available	Lenses available	Film types available	Oblique vertical	1:50 000 photography on 9" X 9"	Lenses available for 1:50 000	Number of camera ports for 1:50 000	Active in
Pacific Survey Corp. 1409 West Pender Vancouver, B.C. V6G 2S4	2-9X9 Zeiss	153 mm 305 mm	BW, NC+, NC-, CIR	Vertical	No			Canada, west of Saskatchewan
					See also Northway Survey			
Photosur Inc. 130 Quest Sherbrooke, Montreal, P.Q. H3A 2R5 - Part of Lavalin Group (International)	4-9X9 WILD RC10 RC8 35 mm Thermal scanner Proton magnetometer	88, 152 mm N.A.	BW, NC+, NC- CIR	Vertical	Yes	88, 152 mm	2	Worldwide
Northway - Gestault Survey Corp. 1450 O'Connor Toronto, Ont. M4B 2V2 See Also Atlantic Survey Pacific Survey	Various - 35 mm (Special) - Spectral data multi-spectral camera	85, 152 mm	BW, NC+, NC-, CIR	Oblique, vertical	Yes	85, 152 mm	2	Worldwide if economical

TABLE 1. (cont.) SUMMARY OF AIR SURVEY COMPANIES ACTIVE IN REMOTE SENSING

Company	Sensors available	Lenses available	Film types available	Oblique vertical	1:50 000 photography on 9" X 9"	Lenses available for 1:50 000	Number of camera ports for 1:50 000	Active in
Northwest Survey Corp. Int'l Ltd. 17203-103 Ave. Edmonton, Alta.	3-9X9 WILD RC10 RC8 Thermal scanner	3 1/2, 6"	BW, NC+, NC-, CIR	Oblique, vertical	Yes	3 1/2, 6"	2	Worldwide, offices in Whitehorse, Yukon, & Yellowknife, Northwest Territories
Prairie Agriphoto Ltd. P.O. Box 817 Carman, Man. R0G 0J0	Various-70 mm Hasselblad	40, 50, 80 mm	BW, NC+, NC- CIR	Oblique, vertical	No			Manitoba Saskatchewan
Terra Surveys 2060 Walkley Rd. Ottawa, Ont. K1G 3P5	2-9X9 WILD RC10 RC9 Various-35 mm	88, 152 mm 9-50 mm	BW, NC+, NC-, CIR	Vertical	Yes	88 mm	2-IN DC3 A/C	Worldwide, offices in U.S.A., South Africa, Australia, Guyana

TABLE 2. SCALE FACTOR RATIOS BETWEEN HIGHER AND LOWER ALTITUDE AERIAL PHOTOGRAPHS[1]

Lower altitude	Higher altitude Kodak 2405 B&W print	Kodak 2424 B&W/IR print	Kodak 2445 Col. neg. print	Kodak 2448 Col. pos. transparency Original	Duplicate	Kodak 2443 Col. IR transparency Original	Duplicate
Kodak 2405	1.00	1.26	1.71	1.45	1.75	1.60	2.00
Kodak 2424		1.00	1.36	1.16	1.40	1.28	1.60
Kodak 2445			1.00	0.85	1.11	0.94	1.17
Kodak 2448 (original)				1.00	1.30	1.10	1.38

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[1] The following costs have been included in the calculations: film purchase, processing, and reproduction (continuous contact duplicating) where applicable. All calculations are based on 1979 National Air Photo Library costs converted to a per foot basis.

FORESTRY APPLICATIONS OF MEDIUM- AND SMALL-SCALE AERIAL PHOTOGRAPHS

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ABSTRACT

The forest industry has played an active role in the development of airborne remote sensing in Canada, and aerial photography is now a widely accepted technological tool for the acquisition of forest resource data. In practical application the stereoscopic analysis of black-and-white and color aerial photographs is accepted as a rapid, accurate, and economic survey method to provide essential information required in logging operations, reforestation, forest engineering, or environmental assessment.

This paper describes the application of air photo analysis techniques and extraction of quantitative and qualitative information on forest cover, physical characteristics of forest land, water resources, and significant site-specific features associated with the operating area. Selected examples demonstrate the usefulness of medium- and large-scale aerial photography in various phases of forestry operations.

INTRODUCTION

The year 1979 marks an important anniversary in the history of aerial photography in Canada. Exactly 60 years ago, in the summer of 1919, Ellwood Wilson, Chief Forester of the Laurentian Paper Company, arranged through the St. Maurice Protective Association a loan of two Curtiss HS-2L flying boats to assess their usefulness for forest fire patrols and to check the spread of spruce budworm infestations. In addition to making notes and sketches of features observed during the flight, he used a hand-held camera to obtain a number of photographs of the company's limits. This first attempt proved to be quite successful; after seeing the wealth of information contained in a single aerial photography, Wilson became a most enthusiastic promoter of aircraft and aerial photography for forest surveys in Canada.

The introduction of aerial photography and development of photo interpretation techniques produced drastic changes in traditional "timber cruising", which often was done by simply "walking" the area and ocularly estimating the available timber. Since a reliable volume estimate was considered a prerequisite to successful lumber operation, the aircraft and aerial photography soon were accepted as convenient inventory tools. The practical use of aerial photography in Canadian forestry has progressed gradually from a substitute for the map and aerial sketching during the early 1920's to an important source of forestry information several years later.

This presentation is an overview of some practical uses of aerial photography in the acquisition of essential data for management of forest land. It includes a summary of the basic characteristics of aerial photographs, a brief description of photo interpretation procedures, and selected examples to illustrate the application of these procedures in recent surveys conducted at various intensity levels.

AERIAL PHOTOGRAPHY AS A SOURCE OF INFORMATION

Aerial photogaphy is the best known and most widely used product of the photographic remote sensing system. It presents a segment of the earth's surface recorded on a sensitized film via an optical system from an airborne platform. Basic characteristics of aerial photographs may be related to imaging systems, geometry, scale, spectral band, season, and hard copy, as shown in Table 1.

Most common in forest surveys is the conventional (23 cm X 23 cm), vertical, medium- or small-scale panchromatic photography flown during the late spring or summer at a specified scale.

The scale of a photograph refers to the "representative fraction" (RF), which indicates the ratio of a distance on the photograph to its corresponding distance on the ground. The RF is the relationship between the focal length of the lens and the height of the aircraft above the ground ($RF = \frac{f}{H}$).

By their "representative fraction", aerial photographs are grouped into small, medium, and large scales:

Small scale: smaller than 1:30 000
Medium scale: from 1:10 000 to 1:30 000
Large scale: larger than 1:10 000

This grouping is arbitrary and quite subjective. Designations have changed several times with the increased working altitude of the aircraft and development of new optical systems. Between 1919 and 1928, for example, the smallest available scales of aerial photography, with an 8.25-inch focal length, were 1:9 000 and then 1:12-000. In 1928, with the introduction of Fairchild Seaplane, the smallest possible scale was extended to 1:14-500, and after 1945, with the 6-inch optical system, it was possible to obtain conventional photography at the scales of 1:31 680, 1:40 000, and 1:50 000. In the early 1960's, limited coverage of the Atlantic coastal area at the scale of 1:80 000 was photographed by the RAF, and portions of Ontario and the eastern Arctic were photographed by the U-2 overflights. These photographs were confidential or had a restricted distribution. In 1970, for the first time, extensive coverage of over 2 million km^2 of western Canada was obtained at the scale of 1:80 000 for the LIFT program, with a short focal length optical system (f = 80 mm), and a year later for the Mackenzie pipeline corridor study. At the same time, as support for the experimental ERTS research projects, the Airborne Unit of CCRS provided photo coverage at scales ranging from 1:100 000 to 1:160 000, using a multicamera system in CF-100 military aircraft.

In view of these changes, a tentative grouping of aerial photographs by scales may be presented as follows:

Ultrasmall scale: smaller than 1:80 000
Small scale: from 1:30 000 to 1:80 000
Medium scale: from 1:10 000 to 1:30 000
Large scale: from 1:2 000 to 1:10 000
Very large or extra large scales: larger than 1:2 000

Conventional small-scale photo coverage (1:40 000 or 1:60 000) now is available for all parts of Canada. A complete (and often repetitive) coverage of forest areas is available also at the scales of 1:15 840 or 1:31 680 from flights for the provincial forest inventories.

The National Air Photo Library (NAPL) in Ottawa, officially established in 1925, is the central depository for aerial photography in Canada. It maintains a complete record of photo coverage ("A" series) obtained by the Canadian aerial surveying industry for the federal government. The roll numbers usually identify the year of photography; for example, roll number "A 19384" means that the photography was obtained in 1966. The 1979 photography starts with Roll No. 25086.

Some of the provinces, such as British Columbia, Alberta, Ontario, and Quebec, maintain provincial photo libraries and indexing systems.

Natural resource industries, municipalities, educational institutions, and research organizations often contract or take their own photography.

Almost all aerial photography in Canada is done by the aerial survey companies, members of the Canadian Association of Aerial Surveyors, which have an excellent national and international reputation.

Extraction of essential information from aerial photographs for forest surveys, resource inventories, or terrain analyses is performed by the trained professional and technical staff of the user or by the consulting industry.

EXTRACTION OF INFORMATION FROM AERIAL PHOTOGRAPHS

In the early 1920's, aerial photography came to be regarded not as a map substitute but as an important source of information that can be measured, counted, described, and translated into a useable form for a specific purpose or can be interpreted easily. The interpretation of aerial photographs became an essential function of the practical application of aerial photography to produce useful information. The principal process of photo interpretation includes the analysis, measurement, and classification of observed ground features represented on the photographs as patterns of grey tones or hues of color. It involves detection, recognition, and grouping of image elements by diagnostic significance for positive identification of the actual or ground conditions they represent.

In order to interpret an image and to extract the required information, the image components must be recognized and identified. The identification is a deductive process, which requires a systematic analysis of detected image components. A three-dimensional study of individual pattern elements such as shape, size, tone, texture, shadow, and spatial arrangement or the interrelationship of these elements provides diagnostic characteristics for the identification of specific vegetation or terrain features. In actual air photo analysis, a single element or several elements may be listed as diagnostic features; for example, the shape and size of an object at a known scale of photography are usually important indicators for estimating the height of a forest stand or the identification of geomorphic land forms. Tone and color are also useful indicators for the recognition of forest types, species composition, or drainage conditions of the land surface. Texture in an aerial photograph, created by the repetition of small objects such as individual trees, provides reliable clues for the identification of coniferous and deciduous forest types. Shadow is often an important element in the recognition of a particular tree species. The spatial arrangement or relationship to other objects forms a distinct pattern on an aerial photograph and often is used as a reliable indicator to determine the moisture conditions of the land, shallow soils over bedrock, or to infer the species composition of forest types.

FORESTRY PHOTO INTERPRETATION

In the development of photo interpretation techniques and aerial survey methodology best suited to Canadian conditions, the CFS has played a leading role from the very beginning. It pioneered the development and testing of specifications for aerial photography, instrumentation for the extraction of essential data from aerial photographs and transfer to the map, simplification of combined photo-field procedures, compilation of volumetric data, and the requirement of stereoscopic examination techniques for the recognition of tree species, delineation of forest types, or basic characteristics of forest land (Seely 1957, Parry 1973).

Two nation-wide forest resource surveys carried out in Canada under the federal-provincial forestry agreements have contributed greatly to the advancement of remote sensing technology in forestry: the forest inventories of some 3 000 000 km^2 in 1949 and the Canada Land Inventory Classification Program involving a 2 500 000-km^2 area in 1963. Both surveys were conducted by the CFS in cooperation with the provinces and were based almost entirely on the application of aerial photography. These surveys provided an excellent opportunity for a large number of Canadian foresters to participate in operational application of remote sensing and to receive training in practical aspects of photo interpretation and resource mapping (Gimbarzevsky 1972).

Forestry photo interpretation employs the image analysis techniques to provide essential information on tree species, height, density, and other parameters required for accurate determination of quality, quantity, and areal extent of the forest resource. Although the working procedures at present employed in Canada may vary from region to region, the general method is essentially the same, involving the identification, measurement, and classification of forest resources from a systematic analysis of diagnostic characteristics portrayed on a stereoscopic model of the land surface. The end product of the forest appraisal process is usually a forest map and quantification of inventory data compiled according to the specific needs of the survey. The scale and type of aerial photography used in photo interpretation depend on the amount of required detail, size of the area to be surveyed, or available resources. The time frame for the acquisition of resource data is often also an important factor in the selection of survey intensity level and appropriate scale of aerial photography.

INTENSITY LEVELS OF FOREST SURVEYS

The appraisal of forest resources may be conducted as reconnaissance, management, or operating surveys, indicating the intensity level of presented resource data. In addition, there are special surveys, designed to provide information for some specific problems.

RECONNAISSANCE AERIAL SURVEY

The reconnaissance or exploratory aerial surveys usually are conducted to acquire general resource information on extensive areas for broad initial planning or formulation of policy. This survey level is used also for design of more detailed inventories. Full use generally is made of small-scale photography (1:40 000, 1: 60 000) to delineate broad landscape units, distribution of forest cover, or access for field investigation. A quick overview of a large area often is obtained by assembling alternate photographs into a stapled mosaic and using matching prints for stereoscopic viewing to delineate broad patterns of physiographic and vegetation features, as illustrated in Figure 1.

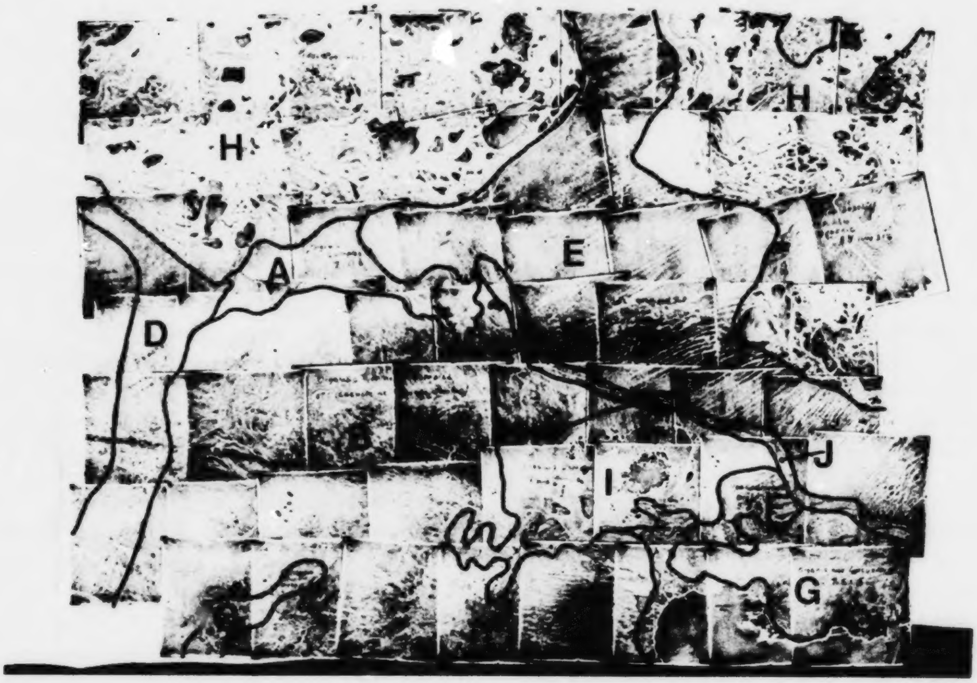

Figure 1. Stapled mosaic provides a quick overview of some 8 000 km^2 area of delineation of broad physiographic units and forest cover. Location: NTS 63F, Man.

The survey level is based almost entirely on photo interpretation techniques to provide sufficient information for rough estimates of major resource characteristics, such as forested and nonforested areas, dominant forest types, broad merchantibility classes, burnt-over or logged areas, general physiographic features, etc. Usually, very little or no fieldwork is involved.

MANAGEMENT AERIAL SURVEY LEVEL

Aerial surveys for management purposes are designed to provide detailed estimates and descriptions of major forest resource features to facilitate management decisions. The survey procedures involve a combined effort of photo interpretation and fieldwork. A stereoscopic analysis of medium-scale aerial photographs (1:15 840 or smaller) and stratification of the forest land into forest types or land productivity classes is based on the recognition of tree species and measurements or estimation of heights, crown diameter or stand density, topography, soil texture, and drainage conditions according to prearranged standards. Fieldwork or collection of "ground truth" is an essential and the most expensive part of any aerial survey and requires proper planning and preparation. As there is no substitute for field experience, the interpreter who worked on the preliminary classification usually takes part in field verification to confirm previous results or to make revisions or corrections, where necessary.

The final results are presented as forest cover types with or without indication of productivity class or as land units with superimposed forest types. Forest cover types are usually stratified by the species or species groups, density of the stand, average height classes, stand structure and condition classes. Productivity of the forest type may be indicated as a site class or classified by dominant physical characteristics of land units.

Figures 2, 3, and 4 are examples of interpreted aerial photographs illustrating a common use of aerial photographs at the management survey level.

OPERATING AERIAL SURVEY LEVEL

This survey level is intended to provide the detailed, local data required to assess the quantity, quality, use sensitivity, etc., of the forest land resources and their treatment needs. Medium-scale aerial photography (1:10 000, 1:12 000, or 1:15 840) is used for fine stratification by individual species or species composition, height classes, density, age classes, and volume per hectare classes. The operational survey level is used also for delineation of forest site classes to indicate actual productivity of map units, sites with regeneration difficulties, naturally infertile sites, sites susceptible to erosion or cutting hazards, terrain units suitable for heavy-duty road construction and summer logging operations, or land units by terrain roughness, slopes, and obstacles for planning mechanical logging and planting (Figure 5).

SPECIAL AERIAL SURVEYS

These surveys, customarily designed for specific single purposes, may be conducted at any intensity level and, in addition to conventional photo coverage, often require complementary aerial photography best suited for a particular problem. The color photography, color infrared, modified infrared, or a multidate coverage, for example, provide a practical tool for damage appraisal, monitoring and assessment of depletion, determination of nonconsumptive values of forest land, erosion control, etc.

CONCLUSION

Aerial photography, since its introduction in 1919, has become a reliable, economical, and efficient technological tool in forest surveys. The photo interpretation technique based on a combined effort of fieldwork and stereoscopic analysis has become a methodical and systematic data acquisition process: the work usually begins with the recognition of known, general features, and proceeds gradually toward identification, measurement, and classification of less familiar complex conditions.

Although the inventory needs will change with the intensification of forest management and some modifications will be required to the present photo interpretation techniques and methods, conventional aerial photography will continue to be the most dependable remote sensing tool in resource surveys, particularly in forest inventories at the operational level and to provide ground truth for processing information from nonphotographic sensors.

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Table 1. Basic characteristics of aerial photography

Imaging systems (cameras)	Geometry	Scales	Spectral bands	Season of photography	Hard copy
- Conventional format: (23 cm X 23 cm)	- Vertical	- Ultrasmall (< 1:80 000)	- Panchromatic	- Spring	- Contact prints - paper - transparency
- Small format: - 70 mm - 35 mm	- Oblique - low - high	- Small (1:30 000 - 1:80 000)	- Infrared	- Summer	- Enlargement
- Panoramic	- Trimetrogon	- Medium (1:10 000 - 1:30 000)	- Color-true	- Fall	- Reduction
- Continuous strip		- Large (1:2 000 - 1:10 000)	- Color IR	- Winter	- Rectified prints
- Multicamera		- Very Large (>1:2 000)	- Multispectral		- Other photos
					- Enhanced prints

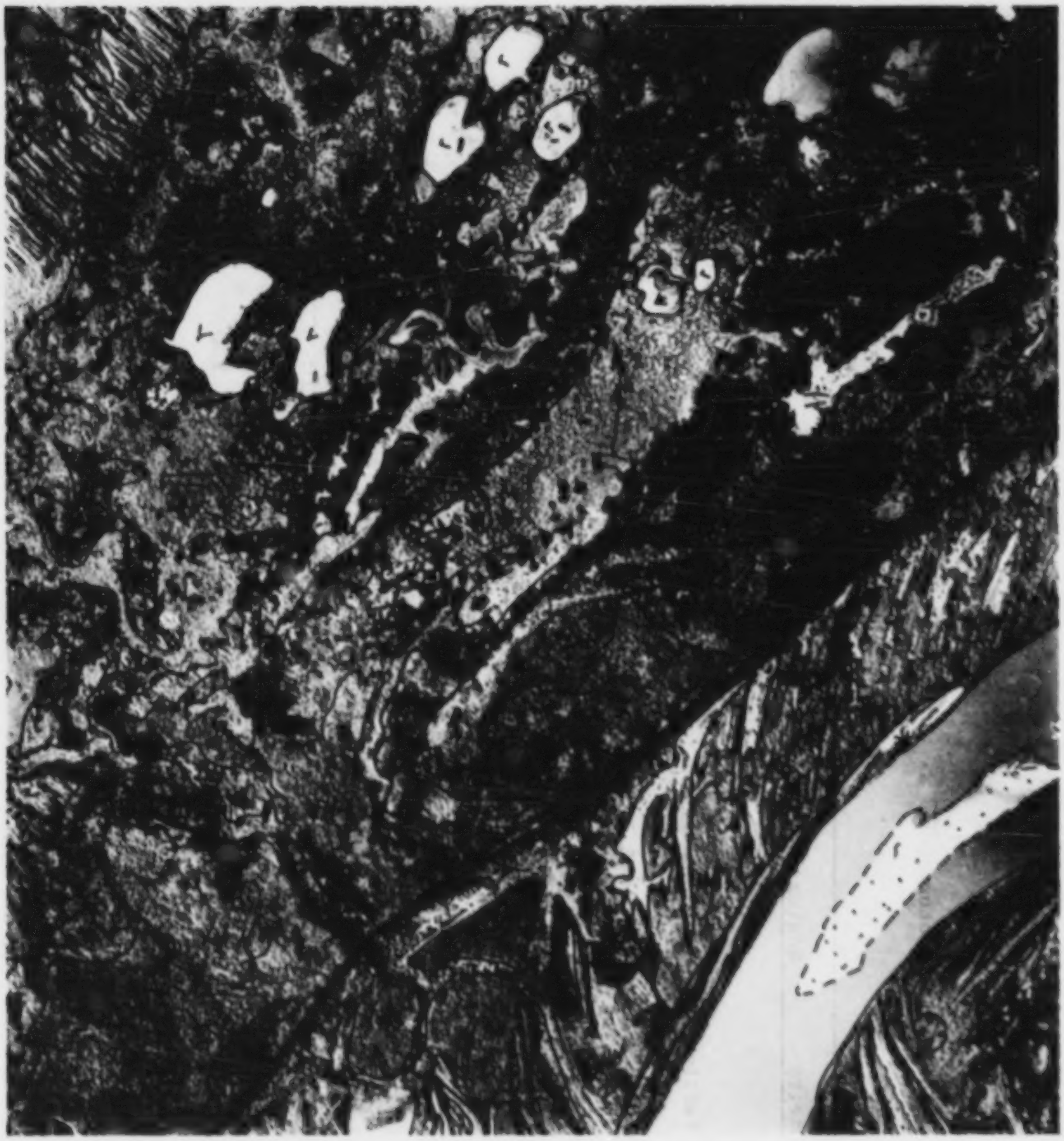

Figure 2. Aerial photograph interpreted for a management survey.

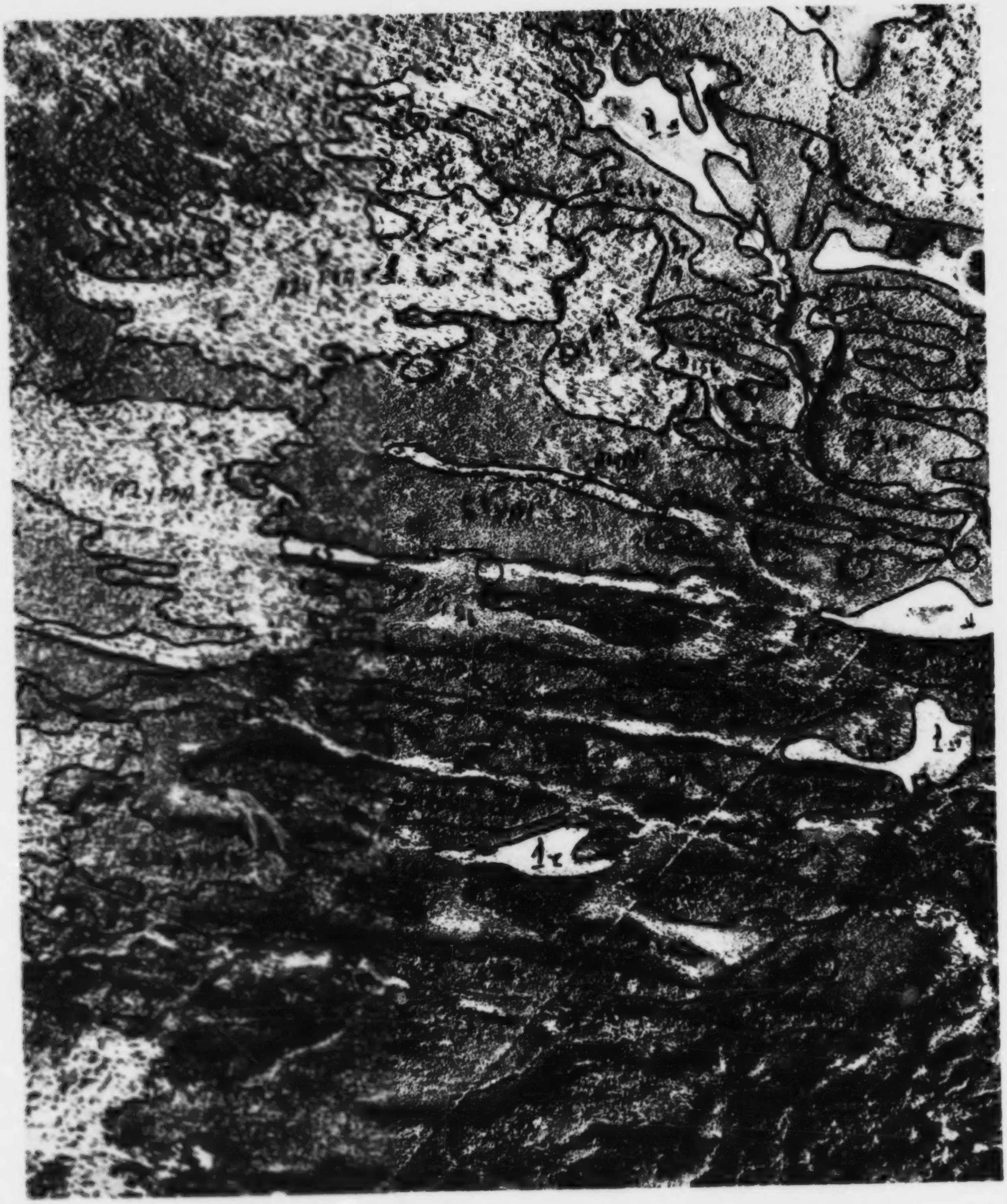

Figure 3. Aerial photograph interpreted for a management survey.

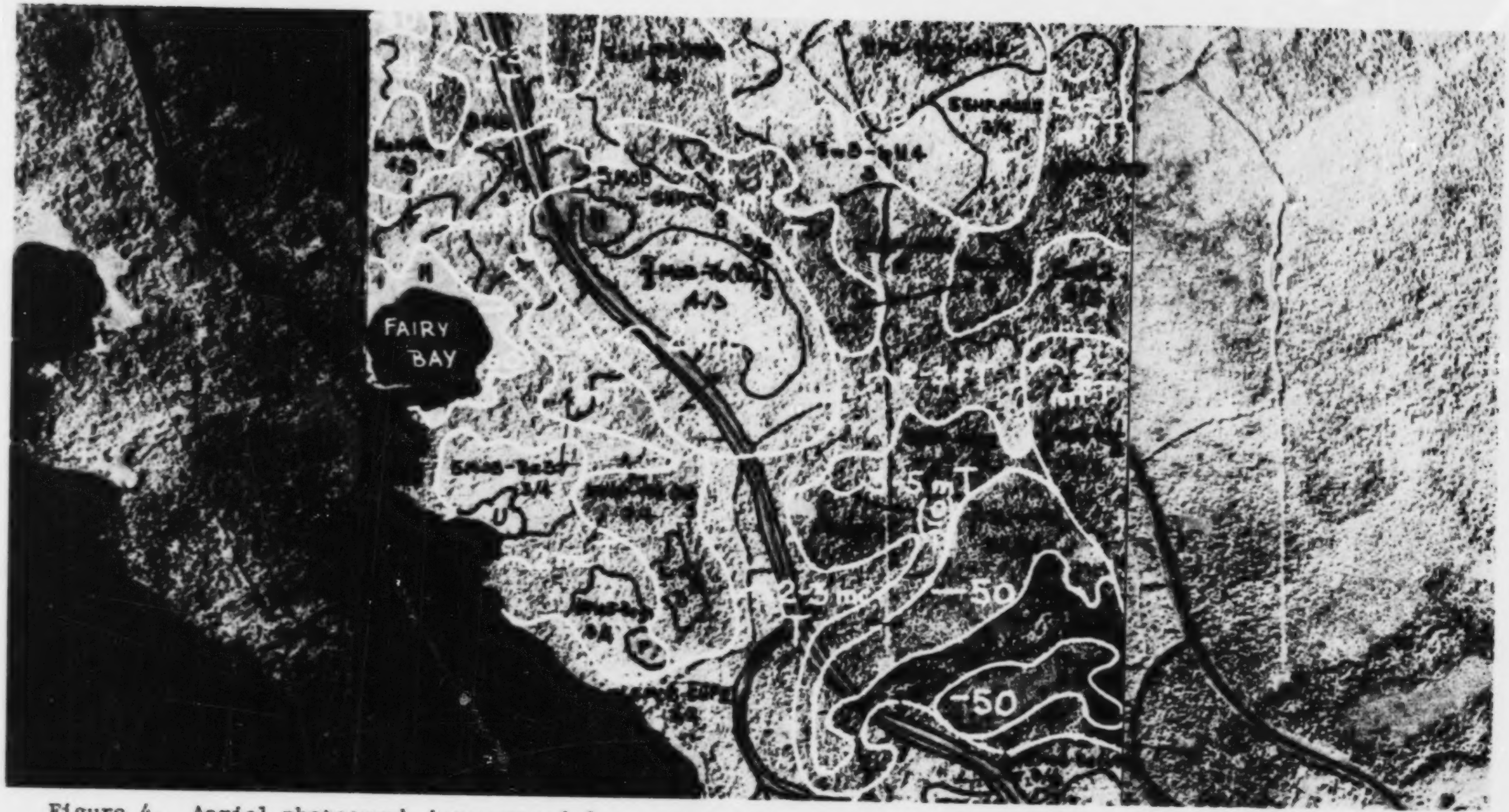
FAIRY BAY
-50
-50

Figure 4. Aerial photograph interpreted for a management survey.

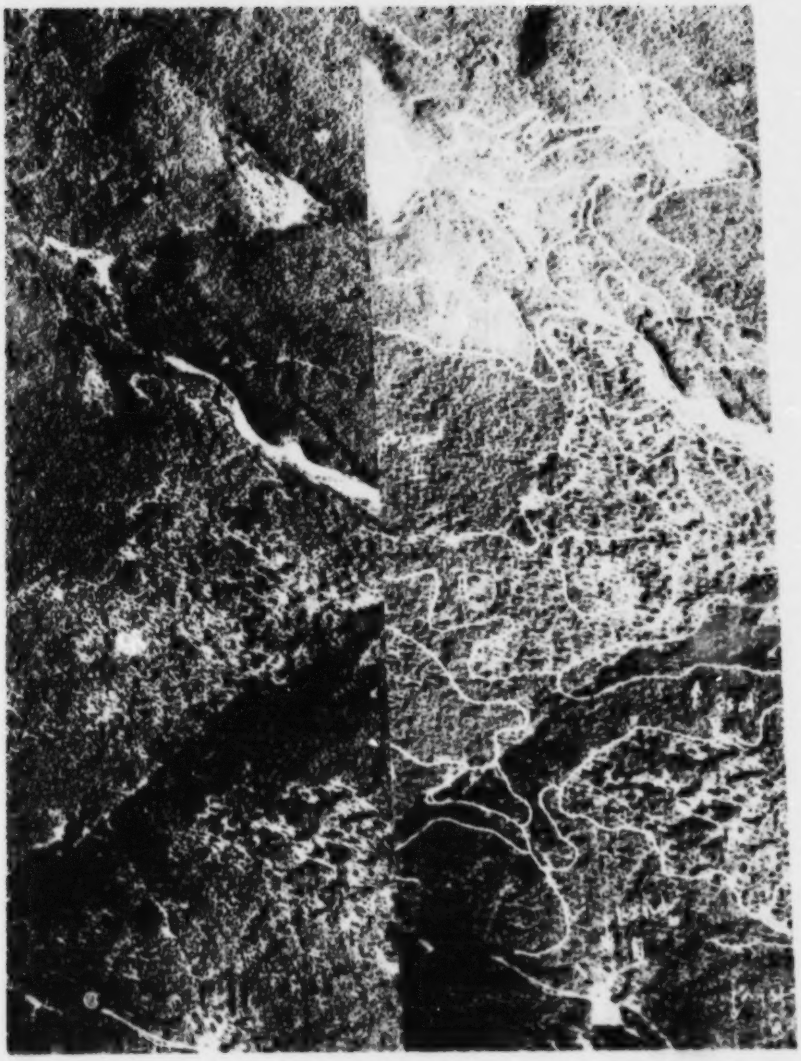

Figure 5. Aerial photograph interpreted for an operational survey.

LARGE-SCALE PHOTO SAMPLING

Chairman: C. Bricker

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A.H. Aldred
P.G. Williams
C.L. Kirby and R.J. Hall
H. Bradatsch

LARGE-SCALE PHOTOGRAPHY FOR FOREST INVENTORY: PROBLEMS AND LIMITATIONS

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ABSTRACT

Several investigators have developed successful methods and systems for taking and analyzing large-scale photography for inventory purposes. The methodology being developed by the Ontario Centre for Remote Sensing is still in the research stage. The results so far indicate specific areas where improvement is needed before practical applications may be considered. Aside from photogrammetric problems, it seems that the parameters of the dbh estimator are stand specific and vary considerably from plot to plot within the same stand. Photographic and ground data collected during the past 2 years are analyzed to demonstrate this problem and determine its extent.

INTRODUCTION

Since 1975, the Ontario Centre for Remote Sensing in cooperation with the Timber Sales Branch of the Ministry of Natural Resources has been involved in the development of a large-scale aerial photo sampling method that could complement or possibly replace operational cruising on the ground. This method will, in essence, replace all inventory ground data with either measurements or estimates of the required variables based only on photogrammetric measurements.

There are two equally important aspects to this approach:

1. The equipment and methods used to acquire and measure the photography must be capable of producing accurate and precise measurements of the photographed objects. This is strictly a photogrammetric problem, although an unconventional one.
2. The variables measured on the photographs must be suitable for estimating the variables required for the particular inventory application.

During the past two years, enough data has been collected to evaluate the performance of the method in the above terms. It seems that improvement is needed in both aspects before the method can be put to practical use.

Before each of these topics is discussed, a brief description of the development of the equipment and method at present being used is required.

DEVELOPMENT OF THE EQUIPMENT AND METHOD FOR LARGE-SCALE PHOTO SAMPLING

At the beginning of the aerial cruising program, the emphasis was placed on direct measurement of the heights and diameters of deciduous trees on winter photography (Zsilinszky and Palabekiroglu 1975). First 35-mm, then 70-mm photography was used. Measurements were performed on a first-order stereoplotter. When the futility of applying this approach to the measurement of conifers was realized, it was abandoned in favor of measuring the heights and crown areas of individual trees on summer photography. To handle the large number of points required for crown area measurements, a digitizer and a programmable calculator were added to the plotter.

To evaluate the feasibility of estimating dbh (or volume) via regression height and crown area, in the past 2 years 40 test sites have been photographed and measured on the ground and on the photographs. The test sites were located in pure stands of the most common boreal species.

Panchromatic photography of short strips transecting preselected stands was taken with a 70-mm Vinten camera equipped with a 6-inch lens. The contact scale was approximately 1:1500.

More-or-less-rectangular plots with an average of 0.1 ha were selected on the ground. All trees within the plot boundaries were tagged and identified on the photographs. Diameter measurements were taken of all the trees and height measurements of about one-third of the trees.

The photo measurements were taken with a Wild A-9 stereoplotter interfaced with a Wild EK-22 digitizer and a Hewlett-Packard 9815A programmable calculator. Positive contact transparencies of the stereo pair containing the plot were set up on the plotter. Relative orientation of the model was performed in the usual manner, followed by an approximate absolute orientation. The contact scale of the model was determined from photo measurement of known ground distances. Then, horizontal and vertical scales were calculated. Tree heights and crown areas were produced by the calculator when the model coordinates of the treetop, base, and points along the crown perimeter were supplied.

ANALYSIS OF THE RESULTS

Processing and analysis of the aerial cruise data, which is essentially a listing by species, height, and crown area of all visible trees within a plot of known area, was done by Dr. J.A. Mervart of the Timber Sales Branch, MNR.

With the requirements of operational cruising in mind, one of the main concerns was how specific the regression estimators were with regard to individual species and, most of all, to individual stands of the same species. The other concern was how well the aerial measurement technique performed in terms of accuracy.

In view of the above concerns, the study was restricted for the time being to the following simple model originally proposed by Aldred and Sayn-Wittgenstein (1972):

$$\widehat{dbh} \text{ (or } \widehat{vol}) = B_o + B_1 \bullet HT \sqrt{CA}$$

Dbh is the estimated diameter, HT is the tree height, CA is the crown area, B_o and B_1 are the regression parameters.

In the course of the analysis, dbh distributions, basal areas, gross total volumes, and dbh-height curves were calculated for each plot from both the ground and aerial data. Some of the plots in the 1978 trials were measured independently by two plotter operators, giving two sets of aerial data.

Results of the analysis regarding the precision of the aerial cruise and the specificity of the estimators can be summarized as follows (J.A. Mervart, personal communication, 1979):

1. Standard error about the regression of dbh on $HT\sqrt{CA}$ ranged between 5% and 15% of the mean.
2. Estimate of height appears to be the most vulnerable part of the aerial cruise.
3. The dbh estimators appear to be species specific and site specific.
4. A comparison of the independent measurements indicates that the photo measurements are not free from personal bias.
5. The estimated basal area per hectare figues were found to be within ±3% of the correct values.
6. The volume per hectare figures were much less reliable due to the influence of inaccurate height measurements.

ACCURACY AND PRECISION OF THE PHOTO MEASUREMENTS

Analysis of the aerial and ground data indicated that the accuracy of height measurements is far from acceptable. There was a general tendency to overestimate the heights. In some plots, heights were overestimated by as much as 4 metres. A comparison of the aerial and ground dbh distributions indicated that, in addition to the general overestimation of heights, small trees were overestimated more than tall trees.

A comparison of the height measurements of individual trees taken by two independent operators showed an enormous scatter, while the crown area measurements of the two operators were in agreement.

The difficulties encountered in height measurements led to several conclusions. Differences between independent measurements of the same trees can be associated with the measurement procedure. While the treetop is usually clearly defined, the ground level is often not; therefore, the lack of adequate detail near the tree base---especially in dense stands---makes the ground-level measurement the suspected cause of the discrepancies.

As for the more or less systematic overestimation of heights and distortions of the height-dbh curves, the problem appears to be related to lack of tip and tilt control in the photography and in the measurement procedure.

Because of the small base-height ratio of the photography, differential Y-tilt errors have a serious effect on the accuracy of model height measurements by distortion of the photo base. The model scales determined from distances measured on the ground and from the photos are also influenced by differential tilt error. The effects of the error on scale and model height are such that they tend to cancel each other when the actual heights are calculated.

Because the height is calculated as the difference between the elevation of the tree base and the elevation of the treetop, warping of the model caused by differential tilt error introduces an error similar to the one encountered when measuring leaning trees on the ground. Depending on the direction of the tilt, trees in the warped model will lean inward or outward. A characteristic feature of the height measurement error due to differential tilt error is that the vertical model scale changes with the height above ground. Depending on the direction of the differential tilt, the scale changes directly (convergent tilt) or inversely (divergent tilt) with the height of the measured objects. As a result, small trees will be underestimated relative to the tall ones if the tilt is convergent, and tall trees underestimated with respect to small ones in the case of divergent tilt. This seems to be in agreement with the results of the study.

The presence of a tilt error resulting in height errors of such magnitude after relative orientation has already been performed is difficult to explain. In theory, it is possible to perform relative orientation solely on the basis of parallax distribution in the model. As long as the relative orientation is accurate, and the tilt of the model does not exceed 5^{0}, accurate height measurements can be expected.

It appears that too much reliance on the optical and mechanical procedures for clearing parallaxes in a stereo pair taken by a lens with unknown distortions is responsible for this problem. Although the Vinten lenses are not of photogrammetric quality, the distortions are probably not large. Still, since the Y-tilt adjustment is rather ineffective for clearing Y parallaxes, elimination of a small amount of parallax requires considerable change in differential tilt.

In aerial sampling, tree height is usually the most powerful variable for diameter or volume estimation; consequently, the reliability of height measurements is absolutely critical for the success of the inventory project.

The solution is to acquire accurate orientation data (altitude and tip and tilt) independent of the photograph and to use it to orient the stereo model. On an analogue plotter it will create visual problems throughout the model, making the measurement process very cumbersome. On analytical instruments, on the other hand, the presence of Y parallaxes does not create any difficulties because of the operating principle.

LARGE-SCALE PHOTO SAMPLING FOR OPERATIONAL INVENTORY

Regardless of the accuracy of the variables measured or estimated from the photographs in terms of individual plots, problems will be encountered when the aerial method is used as an operational survey technique. The aerial method would be required to provide timber volume estimates of relatively high accuracy by individual species and relatively narrow dbh classes on an individual stand basis.

According to our results, however, the dbh estimator is specific to both species and site (or stand). In some cases, estimators for adjacent plots in the same stand significantly differed in their parameters. Using the estimator derived for one plot in another stand would have serious consequences. The pooling of data is acceptable for estimating volume in a large block of stands, but applying it to individual stands would lead to considerable errors. Naturally, if each stand had to be ground sampled in order to derive its specific regression estimator, the aerial method could never become operational. Eliminating or at least minimizing the ground work is one of the main prerequisites for implementing aerial cruising on a larger scale. The feasibility of the aerial method therefore depends on finding a way to predict the parameters of the estimator for any species and for any stand on the basis of stand characteristics measurable on the photos.

So far, the screening of available data did not reveal any close association between the parameters of the dbh estimator and parameters of the height curve, height-crown area ratio, and mean HT $\sqrt{CA}$ for the given stand. On some plots, crown surface was measured as an additional variable. As may be expected, the crown surface and crown area are highly correlated; therefore, inclusion of crown surface in the estimator would not greatly reduce the error.

The search for additional stand information appears promising. The aerial photo measurement method offers an opportunity to derive stand variables other than those used up until now, with relatively little additional effort. The spatial distribution of trees within the plot, crown closure, competition among neighboring trees, etc., could be easily determined as a by-product of the measurement of the main variables.

It is quite conceivable that some of the differences found beteen the parameters of the dbh estimators of similar stands could be explained by the inaccuracy of the measurements. For this reason, the development and testing of new variables should commence only after the problems of obtaining accurate photogrammetric measurements have been satisfactorily solved.

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ADAPTATION OF LARGE-SCALE PHOTOGRAPHY TO ALBERTA'S PROVINCIAL FOREST INVENTORY PROGRAM

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ABSTRACT

Following the demonstration of the capabilities of large-scale photography as an alternative means of collecting sample plot data for timber inventory purposes, the Alberta Forest Service decided to integrate the new technology into its ongoing inventory program. The integration of the techniques required considerable effort to clearly define the user needs, to accommodate and take advantage of existing data and data from other sources, and to adapt the peculiarities of the large-scale photo approach to the current inventory procedures and requirements of Alberta's computer-based inventory compilation system.

WING-TIP CAMERA FOR SAMPLING PHOTOGRAPHY

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ABSTRACT

Integrated Resources Photography has developed a large-scale photography system utilizing 70-mm Vinten cameras installed in the wing tips of a light aircraft. Compared with single camera systems exposed sequentially, the wing-tip configuration exhibits some advantages for forest inventory sampling. A description of the system is presented, and the performance characteristics are discussed.

INTRODUCTION

I am very pleased to have been invited to speak to you concerning my firm's work in ultralarge-scale photography for forest sampling. The firm I represent contracts to produce aerial photography and photogrammetric services, and one of our developments in aerial photography may be of interest in forest inventory work.

We placed vertical-looking cameras on each wing tip of our Cessna 180 aircraft and arranged to fire them simultaneously. This is a variation of the stereometric camera, which is about a century old and was first used in the air by Gene Avery in the late 1950's. It was then developed considerably and turned into an operational tool by Hugh Lyons and Helmut Bradatsch of the B.C. Ministry of Forests in the 1960's and 70's.

QUALITY OF THE STEREO VIEW

I think that the wing-tip camera system has merit, and I would like to discuss some of its characteristics, starting with the quality of the stereo view. The quality of the stereo view can be discussed in terms of the base-to-height ratio or B/H (base being the distance between exposure stations) and the depth of the object field for which a single correlated stereo view is required. For the two illustrations I want to give, I would like to use the distance between a pair of eyes as B, roughly 3 inches.

As a first example, consider that you are holding a pen with the tip pointing toward you. Place the tip about 6 inches from your eyes. Ignore the eye strain, because it is not relevant in the consideration of geometry. The B/H is approximately 1/2, very similar to B/H for topographic photogrammetry using a standard 6-inch mapping camera. Notice that you cannot see the entire depth of the pen in one stereo view. The object field is too deep. You can look at the top 3/4 inch or so as one view, or the bottom 2 inches, but not the entire length of the pen. This kind of viewing geometry is necessary for precision height measurements of about 1/5000 of the flying height; approximately 1/1000 of an inch in the case of the tip of the pen. It is the cause of the vertical exaggeration in normal aerial photography.

Consider another example. Assume that we can look at a person at leisure without being observed. She is about 5 feet away, so the B/H is about 1/20. How deep is the object field---about 6 inches? The depth of the object field is then about 10% of the flying height. I think you will agree that in most respects, the quality of the stereo view that I have described is close to optimum.

If we translate the parameters of B/H and depth of object field from this second example to the wing-tip camera system, a B/H of 1/20 results in a flying height of about 225 metres. An object field with a depth of 10% of the flying height will be 22 metres deep. These figures are obviously very close to what we find when taking large-scale forest sampling photography. The quality of the stereo view of 22-metre-high trees from 225 metres with the wing-tip camera system is analogous to looking at a person 5 feet away.

EASE OF PRODUCTION AND USE

I would like to leave the human eye analogy now and look at some of the characteristics of the wing-tip camera system.

1. Producing the photography is easy. The cameras are always perfectly aligned. The time between exposures does not affect B/H or the stereo view. The pilot can skid around corners or even put one wing up for low oblique views. The vehicle is an inexpensive, small, fixed-wing aircraft. Ease of production and small, fixed-wing aircraft translate into low costs and low prices.

2. Using the photography is easy. The film is contact printed onto 8" X 10" sheets. The two negative rolls are simply spooled in tandem and printed. Transparencies are mounted into individual stereogram cards, 9 cm X 21 cm. It is not necessary to baseline and rotate the photos because the cameras have been baselined. There is no Ω angle to deal with, and this greatly improves the stereo view when the object field is multilayered; for example, when viewing both the tops of the trees and the ground in one correlated stereo view.

3. The simultaneous exposure freezes dynamic scenes. This is important because the lower the flying height, the more movement there is in the object field; for example, swaying trees, water surfaces, people, animals, and smoke. An interesting example of the advantages of this are stereograms we have of sockeye salmon spawning. The simultaneous exposure creates one water surface which can be clearly seen in stereo, and it stops the fish as they swim, so they too can be seen in stereo.

4. As an interesting aside, low-level wing-tip photography can be used to view power lines. The aircraft can fly parallel to the power line, and the conductor is seen in stereo above the ground. A sequentially exposed single camera must fly across the power line to image the conductors in stereo.

5. Unlike single camera aerial photography, it is possible to increase the photo scale simply by using longer focal length lenses. Because the Ω angle is rigidly controlled, there is no amplificaiton of the misalignment of principal and conjugate points.

To review briefly, low-level wing-tip photography regularly produces an excellent stereo view, is inexpensive to produce, easy to use, and freezes moving objects. The next consideration is measurement of the subject field, and especially vertical measurements, using large-scale photos in general, and wing-tip photography in particular.

MEASUREMENT CONSIDERATIONS

Consider first the measurement precision that we may reasonably anticipate in photography with this kind of small base-to-height ratio. It is known from topographic mapping practice that heights may be measured with a precision of about 1/5000 of the flying height when B/H is 1/2. This translates into an angular resolution capability of the eye of about 1/220 of a degree. This resolution is probably constant for any B/H, and if it is applied to the situation where B/H is 1/20, as with the wing-tip camera system, the height precision works out to be about 1/600 of the flying height. From 225 metres, therefore, it is reasonable to expect to be able to measure the height of a 22-metre tree to a precision of about ±0.4 metres, roughly the same precision obtained by production techniques for measuring tree heights on the ground.

The type of measurements to be undertaken are, for example, tree heights, crown areas, and horizontal dimensions of sample plots. For such measurements an absolute orientation of the photogrammetric model is not required, so long as the camera axes are vertical within approximately 6^{o}, a generous tolerance. We should not, however, entertain the hope that precision engineering type measurements or contour mapping can be performed using wing-tip photography.

The concept of measurement in terms of the photogrammetric model can be used when talking about measurements made with a parallax bar and the parallax equations, or made in an analogue plotter, or made analytically using a stereo comparator. Restricting ourselves for now to the two-dimensional case, as seen in the elevation view of Fig. 1, the fundamental requirement for measuring or restituting with the photogrammetric model is the knowledge of B, Φ, f, and the plate coordinates where the rays pierce the photo plane.

Normal topographic photogrammetry solves for Φ using the classical relative orientation and for B from ground control. The classical relative orientation procedure starts to fail when B/H is about 1/5, and it becomes very difficult at 1/10. When B/H is 1/20, the classical relative orientation procedure is totally useless. In addition to this, ground control is not available because if we have to visit each site, we might as well measure the trees while we are there.

It is my experience that low-level sampling photography with a B/H large enough for a good relative orientation produces an unsatisfactory stereo view, a bit like the pen held too close to the face. The agencies in Canada doing large-scale photography with a single camera tend to favor the Vinten camera with a 280-mm lens. This combination at 60% forward overlap has a B/H of 1/12; at 80% forward overlap, B/H is about 1/24. In neither case can a good relative orientation be performed to make the photogrammetric model. If you can not do a classical relative orientation to solve for Φ, the use of a height measuring instrument alone such as a foliage penetrating radar altimeter is not sufficient to make a rigorous photogrammetric model, unless you simply assume a value for Φ. From the photogrammetrist's point of view, this is unsatisfactory.

The Northern Forest Research Centre, one of our hosts for this workshop, has developed a photo sampling system that uses a single camera and a radar altimeter. Although this system requires that Φ be assumed to be zero and therefore is not rigorous in a photogrammetric sense, the developers of this system claim that the measurement results are quite adequate for the purpose of measuring forestry sample plots. I would not argue with this assertion, because the adequacy of a measuring system for the intended application is more valid than the photogrammetrist's desire for a rigorous photogrammetric solution.

The Forest Management Institute (FMI) in Ottawa has, in my opinion, obtained the first rigorous solution to the photogrammetric model using ultralarge-scale photography by developing both a foliage penetrating radar altimeter to solve H for each exposure and a gyroscopic tilt indicator that piggybacks on top of the camera to give Φ for each exposure. H and f are used to solve for B'; and B', H, and Φ are used to solve for B. They have all the requirements to make a photogrammetric model.

I believe that the Swiss Forest Research Institute has found the second rigorous solution. It mounted a pair of small cameras rigidly onto the frame of a helicopter. The base is about 8 metres and is transverse to the direction of the flight.

I am somewhat uneasy about performing photogrammetric measurements on photography produced using fore and aft fixed-base cameras mounted on a moving vehicle because of the difficulties in making both cameras fire simultaneously. With a very small B/H ratio, small uncertainties in B amplify into very large uncertainties in the height or z scale of the model. The comments made above, however, also apply to fore and aft fixed-base sampling systems. If the results prove to be adequate for the application, then the system checks out, and it becomes a useful measurement tool.

In agreeing, however, that nonrigorous photogrammetric solutions may be adequate for particular applications, I feel compelled as a photogrammetrist to call attention to a danger. The use of large-scale photography for forest inventory involves the technology of photogrammetry. Even though the measurement precisions required for photo sampling are extremely low when compared with topographic mapping, the photogrammetry is still difficult and complex. Because of the small base-to-height ratios, the procedures must be developed from first principles.

The technology of photogrammetry goes back more than 80 years, and through hard knocks and experience gained at great expense, certain fundamental rules have evolved. One of these rules is that photogrammetric restitution should be performed in a manner that provides not not only simple answers but also sufficient information to allow precision limits to be placed on those simple answers.

Photo sample plot procedures that ignore this fundamental concept should, in my view, receive very close scrutiny. If anyone were to ask my advice on the selection of an airborne camera system for inventory plot measurement, I would encourage the adoption of a system that satisfies the requirements of photogrammetric rigor.

Concerning the wing-tip camera system, we have most of the requirements to make a photogrammetric model, with one exception. The wings flex regularly during flight and Φ therefore is unknown. This flexing does not impair the viewing quality of the photography but it does affect the photogrammetry. We are currently working on an instrument that will indicate Φ directly for each pair of stereo exposures.

A hybrid development of the wing-tip camera system that will produce a rigorous photogrammetric model would be to install a radar altimeter and leave Φ as a mathematical unknown. Using the knowns, B, f, and H, it will be simple to calculate B'. Knowing B, B', and H, Φ may be calculated, and we then have the requirements for a photogrammetric model.

We anticipate that when the equipment for making photogrammetric measurements from wing-tip photography is completed, the wing-tip camera system will be an effective tool for the observation and measurement of small forestry sample plots.

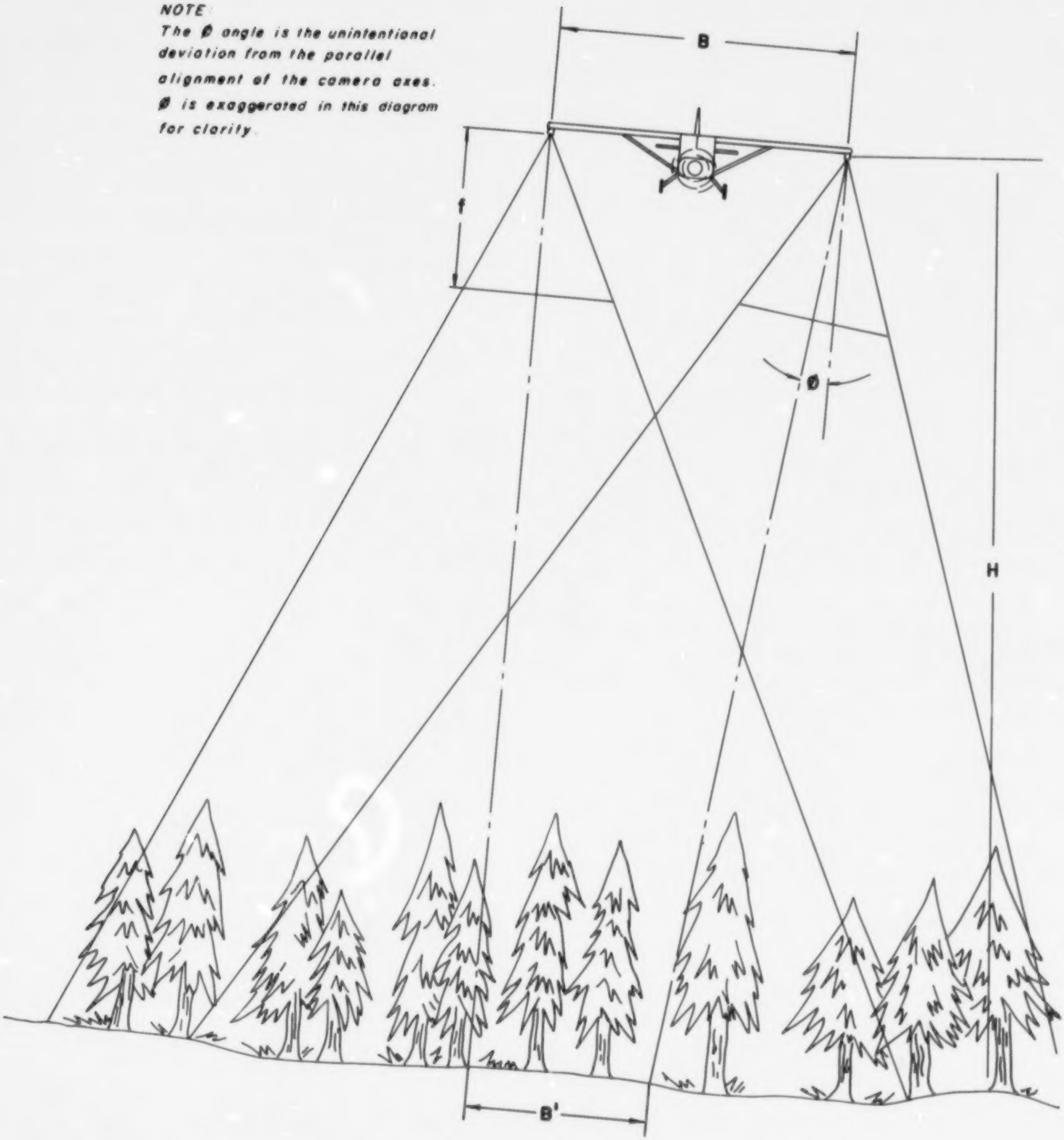
NOTE:
The Ø angle is the unintentional deviation from the parallel alignment of the camera axes. Ø is exaggerated in this diagram for clarity.
B
f
Ø
H
B'

Figure 1. Schematic drawing of I.R.P. Ltd. wing-tip stereo photography.

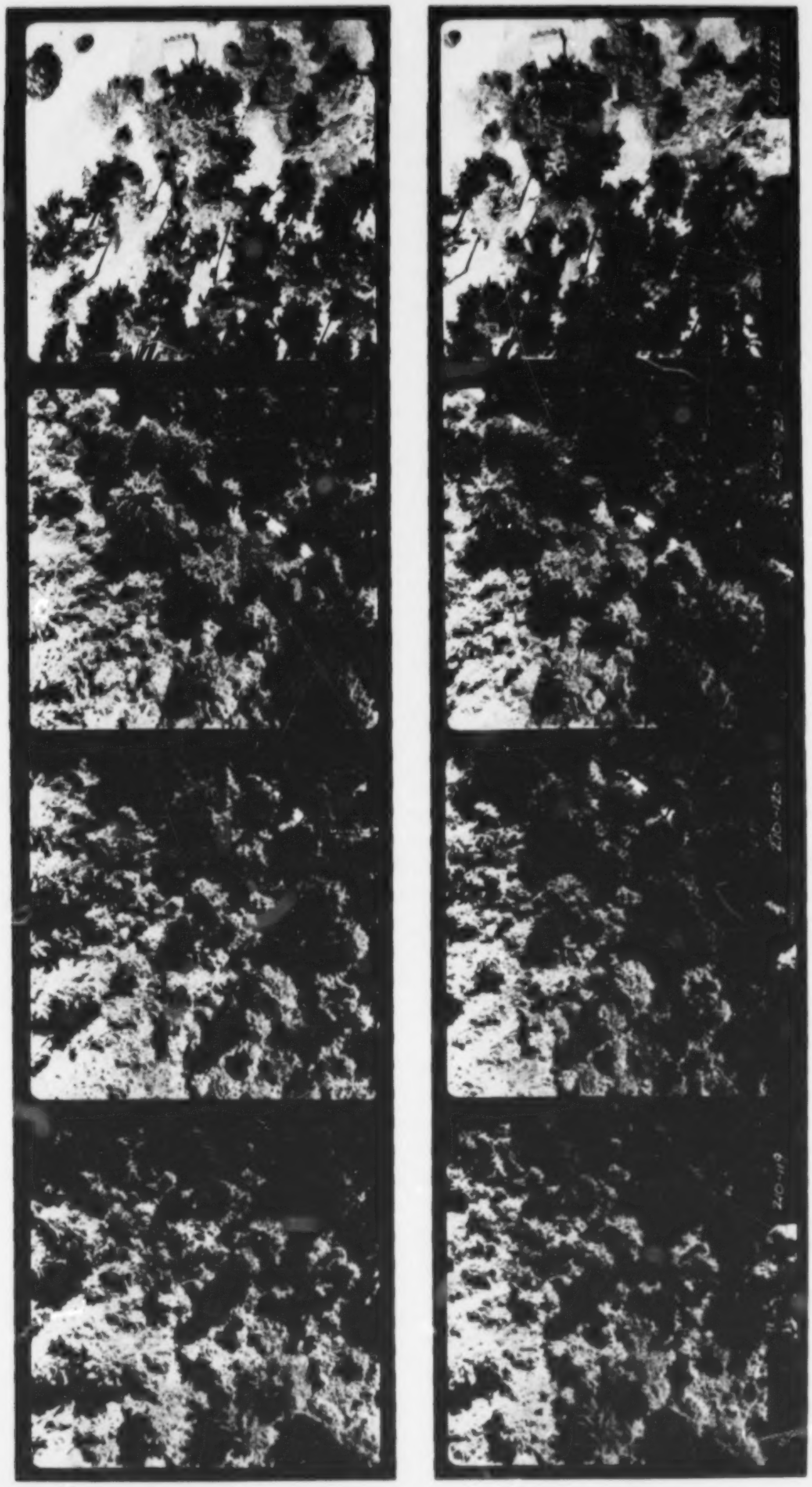
210-122
210-121
210-120
210-119

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Figure 2. The film is contact printed in tandem onto 8" X 10" sheets (shown here actual size).

THE LARGE-SCALE PHOTO SAMPLING SYSTEM AT THE NORTHERN FOREST RESEARCH CENTRE

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ABSTRACT

A description and evaluation of a low-cost aerial camera and interpretation system assembled at NFRC is presented. The camera system consists of a Honeywell radar altimeter, two 70-mm Vinten aerial cameras, and an intervalometer. Height of aircraft above ground is recorded digitally on each exposure taken. Studies have shown that on the average the altimeter is within ±3% of true altitude in open and timbered areas combined for the 45-600 m altitudinal range. Over forested areas, timber bounce may occur, and calibration may be necessary to better estimate desired parameters.

The interpretation system consists of a Hewlett-Packard desk-top computer interfaced to a Carl Zeiss-Jena Interpretoskop, with a parallax measuring device and digitizer. Computer programs have been written to facilitate speedy compilation and summarization of the variables measured. The system has been applied to timber inventory in the measurement and estimation of tree heights, diameters, and volumes, and in the estimation of forest residues, regeneration stocking, and woodpile volumes in millyards.

INTRODUCTION

A large-scale photo (LSP) sampling and interpretation system (Fig. 1) has been developed at the Northern Forest Research Centre (NFRC) in Edmonton. The camera system consists of a Honeywell radar altimeter with digital readout not previously tested for forestry applications, two 70-mm Vinten aerial reconnaissance cameras, and a specially designed intervalometer for forest sampling. The system may be mounted on fixed- or rotary-wing aircraft. At present, it is the only system that may be used at altitudes of 70 m or lower as required for forest regeneration sampling. In addition, the system has been used to obtain timber volume estimates, millyard log-pile volumes, and volumes of forest residue left after logging.

EQUIPMENT

Camera Mount

The Vinten cameras may be mounted on a modified A-11-A camera mount, which requires an aircraft hatch 45 cm or larger in diameter. Quick-release screws permit the cameras to be moved up or down or to be completely removed in flight when lens or filter changes are necessary. L-shaped brackets have been made at NFRC for the Vinten cameras when external mounting is necessary. These brackets have proved to be versatile and have been mounted on a number of different types of helicopters. Vibration with either mount is not a problem because of the high shutter speeds of the cameras.

Cameras

Two types of 70-mm Vinten reconnaissance cameras are used: type 492 has a built-in secondary optical system that permits information on the altimeter reading and time of exposure to 1/100 s to be recorded on the negative; type 518 has optional image motion compensation and a higher framing rate of up to 12 frames per second if desired. The cameras have rotating focal plane shutter blinds that provide shutter speeds of 1/1000 or 1/2000 s, depending on the slit width and the cycling rate. Four different focal length lenses may be attached: 44.5, 77.5, 152.9, and 281.9 mm. The magazines can be changed quickly and have a vacuum platen to hold the film flat. They take a 30-m roll of 70-mm film, which is enough for approximately 500 exposures. The vacuum for the camera is provided by a small pump. In addition, larger capacity magazines may be obtained if required. The cameras are shown in Figs. 1B and 1C.

Intervalometer

The intervalometer (Fig. 1C) used to control the cameras was designed and built at NFRC (van Eck and Bihuniak 1978). It has a sampling feature that permits one camera to group a number of photographs together, to regulate the time between exposures within the group, and to change the interval between groups. With this feature, both cameras can be used to provide sampling photography. For example, in regeneration assessment, one camera with a short 44.5-mm or 77.5-mm focal length lens photographs the track continuously, while the other camera, equipped with a 281.9-mm focal length lens and using the sampling feature, takes stereo triplets or longer bursts intermittently. These triplets or bursts, which have a scale seven or four times larger than the strip photographs (depending on the ratio of the focal lengths of the lenses used), can be used then as aerial sample plots and their positions can be located on the smaller-scale maps or photographs with the aid of the continuous strip photography.

Radar Altimeter

The Honeywell radar altimeter (model AN/APN-194 [v]) is composed of a receiver-transmitter, two antennae, an analog height indicator, and a digital height display on light-emitting diodes. This display is recorded on each photograph through the secondary optics of one of the cameras. The radar altimeter is a lightweight (5 kg), high resolution, short pulse system. Its advanced design provides for a precision of ±3% or better in estimating aircraft height above terrain from 0 to 600 m (Kirby and Hall 1980). The altimeter is not affected by pitch and roll and is without slant range errors. In addition, it has continuous resolution without step errors, complete immunity to Doppler effect, accurate indication over ice and snow-covered surfaces, and all-weather operation in heavy rain or snow. Operating frequency is 4.3 GHz, with a pulse repetition rate of 8.5 kHz. Transmitting wavelength is 6.977 cm. Peak radiated power is 100 W. The transmission antenna contains the energy within an approximately 35° cone-shaped pattern. Smaller cone shapes may be achieved with a different antenna, if required.

Power Supply

The cameras, intervalometer, and radar altimeter require 6 A of current at 24 V DC. Power may be supplied by the aircraft or by two Globe 20 A·h, 12 V gel/cell® aircraft -approved batteries connected in series. This will operate the system for 2 to 3 h.

Interpretation System

The measurement of large-scale aerial photo sampling plots has been facilitated by the interfacing of a Zeiss-Jena Interpretoskop and a Hewlett-Packard 9825A desk-top computer (Figure 1D). The movement of the overhead carriage in X and Y directions is measurable to the nearest 0.25 mm and in the Z direction (parallax measurement) to the nearest 0.01 mm. Measurements of X, Y, and Z can be recorded by the computer at the press of a button. Computer programs have been written to calculate and record individual measurements of tree height, crown area, and tree position and to produce plot maps.

APPLICATIONS

The NFRC large-scale photo sampling system has been applied to four major areas: the estimation of logging residues and wood pile volumes; the estimation of regeneration stocking ≥ 30 cm in height, timber inventory in the measurement of tree height; and the estimation of diameter and volume (Fig. 2).

Estimation of Logging Residues

A small test (Kirby and Hall 1979) was conducted to determine whether logging residues could be estimated from large-scale photographs using the line-intersect method of fuel sampling. The measurement of logging residues is of interest to: 1. fire management personnel for fuel loading and rates of accumulation; 2. silviculturists for site preparation for forest regeneration; and 3. individuals concerned with the utilization of forest residues as an energy source. In application, the method is quite simple since it requires only a diameter tally of the wood on the ground and the length of the sample line in order to estimate forest residues.

In a trial at Hinton, Alberta, on the St. Regis company lease area, color (Kodak 2445 film) aerial photographs were taken in the spring at 60 m above ground to provide a scale of approximately 1:250. Results showed that on two 10-m sample lines, ground and photo volume estimates of residues expressed in m^3/ha were within ±10% (Kirby and Hall 1979).

Factors affecting photo measurement include: logging residues that may have been partially covered by grass, soil, or other slash; ground vegetation; and forest regeneration or its shadows. In terms of production, our small test indicated that a person in the office can measure approximately four times faster than someone on the ground. Consideration must be given, however, to fuel type, fuel loading, and the number of pieces to be tallied, since this will affect the production rate. The test seems to indicate that large-scale photo sampling could be an economical sampling technique for estimating material greater than 25 mm in diameter. A sample line is illustrated in Fig. 2A.

Estimation of Wood Pile Volumes

In 1978, in conjunction with North Canadian Forest Industries Limited of Grande Prairie, Alberta, NFRC established a study to determine the volume of log piles in the millyard (Fig. 2B). Aerial photographs on black-and-white panchromatic film were obtained using a Jet Ranger helicopter at 600 m above ground. Prints were enlarged four times, and the photos were measured on the NFRC interpretation system. Volumes were obtained by an estimating procedure that determined the volume of sections of each log pile.

The main problem in measurement was the presence of shadow. It is recommended, therefore, that the photos be taken during high overcast days to reduce shadow effects.

Estimation of Regeneration Stocking

Large-scale photo sampling (LSP) of coniferous forest regeneration 30 cm and taller is technically possible and may be an economical alternative to ground surveys where access is difficult and costly (Kirby 1980). Those areas that appear stocked on large-scale photographs require no further ground checks, as seedlings not visible on the photographs provide a margin of safety. Evaluation of stocking with LSP techniques may reduce regeneration survey costs by eliminating the need for costly ground surveys of areas that obviously are stocked. In addition, LSP could provide a monitoring capability for subsequent mortality or ingress of regeneration. A disadvantage is that differentiation of tree species such as pine (Pinus spp.), spruce (Picea spp.), and fir (Abies spp). less than 90 cm high is not always possible. The main advantages are that a much larger sample may be obtained (up to 100% coverage) and that precise estimates of stocking may be obtained for coniferous regeneration over 30 cm in height. Fig. 2A shows four 2 X 2 m (4 mil-acre) plots, which may be used in regeneration sampling.

A two-stage photo sampling design is recommended in which two scales (1:250 and 1:1000) of 70-mm aerial photography are obtained simultaneously. The larger-scale (1:250) color photography is used to sample the regeneration at prescribed intervals. The smaller-scale (1:1000) color infrared photography is used for mapping the whole clear-cut to indicate unstocked areas, damage situations, and required stratification for subsequent sampling.

An example of the cost of obtaining large-scale photographs on a clear-cut 200 x 800 m (10 x 40 chains) is as follows: Three sample lines would be obtained at 100-m intervals. This would provide complete coverage at a scale of 1:1000 and 24 photo plots at a scale of 1:250, each having a cluster of 36 2 X 2 m sampling units. The 1979 cost of photo acquisition is approximately $18 per photo plot (cluster of 36 2 X 2 m sampling units) or $27 per hectare, assuming that a locally available helicopter would be used and that ferry charges would be minimal. This is comparable to the average cost in Alberta for a ground survey of a clear-cut, which is usually based on less than 100 2 X 2 m sampling units. The larger sample size with LSP makes possible more accurate and precise estimation of stocking 30 cm and taller. The system is most suitable for assessment of large areas such as done by Ball and Kolabinski (1979) in Saskatchewan.

Tree Height and Timber Volume Estimates

The estimation of timber volume on large-scale photos is dependent upon measures of tree height and/or crown area (Kirby and Johnstone 1970). Figure 2C is an example of an aerial photograph used for photo measurements. To minimize extraneous sources of error such as tip and tilt in aerial photography and its effect on photo measurements of tree height as described by Schut and van Wijk (1965), the following procedures are used:

1. A stable twin-engined aircraft such as a Piper Aztec is used to obtain the aerial photography at an airspeed of 67 m per second (150 mph) to further ensure stability. A shutter speed of 1/2000 s is used to minimize blurring from image motion.

2. A short duration of 1/5 s between sample photo triplets is used to ensure that changes in aircraft attitude between successive exposures will be at a minimum.

Some test results for the Sidney Lake and Braeburn areas in the Yukon were obtained on the accuracy of coniferous tree height measurements between photo and ground (Personal communication, B. Bowlby and D. Morgan, Yukon Lands and Forest Service). In the Sidney Lake area, an average deviation (sum of tree height differences between photo and ground divided by the number of trees) of -0.09 m was calculated using standing tree heights. Approximately 1000 trees were used in this test, with photo measurements that were made on black-and-white aerial photos. When the trees were felled and remeasured, the average deviation was determined to be +0.06 m. In the Braeburn area, color aerial photos were obtained, and 639 trees were measured but not felled. The average deviation was calculated to be +0.23 m. Considering some steep slopes and shadows on the color photos, this error was considered to be quite acceptable. A similar test in Alberta indicates a standard error of ±1.6 m and was based on 67 trees that were not felled to obtained ground heights. A regression plot for the 67 trees is shown in Fig. 3. In this test there was some evidence of timber bounce (where radar signals are affected by vegetation). Calibration of the radar altimeter may be required for each timber type being surveyed. To date, tree height measurements between photo and ground on the average have not exceeded 4%.

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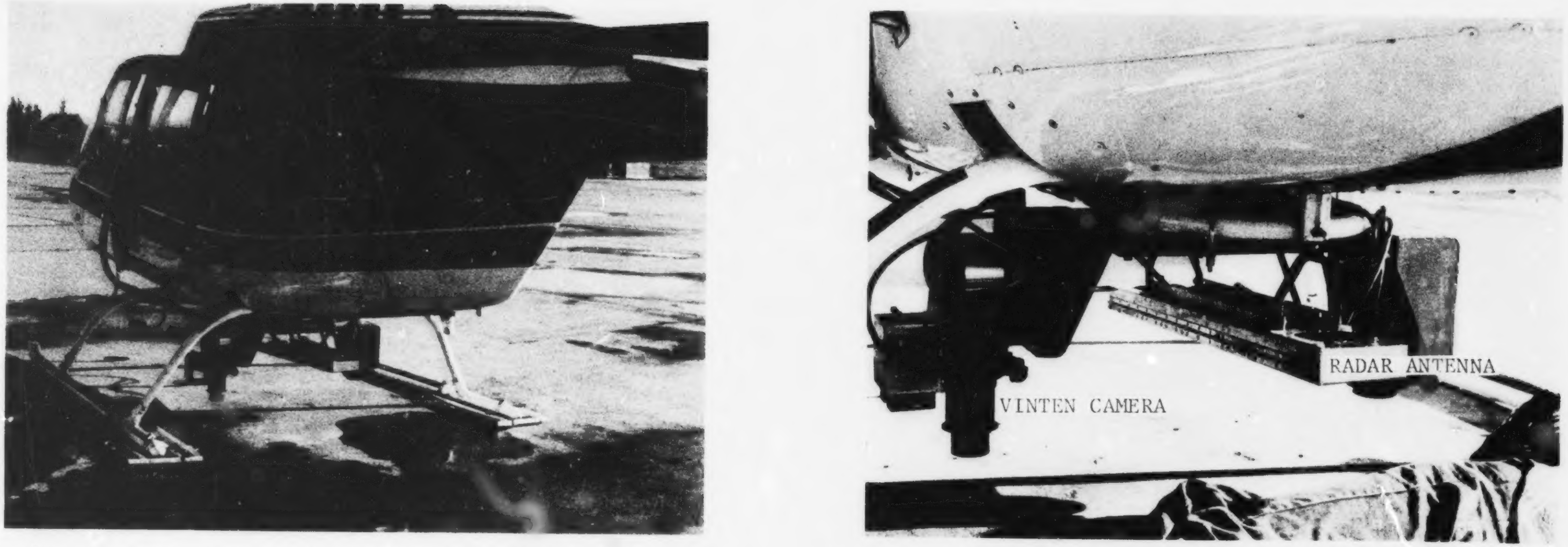
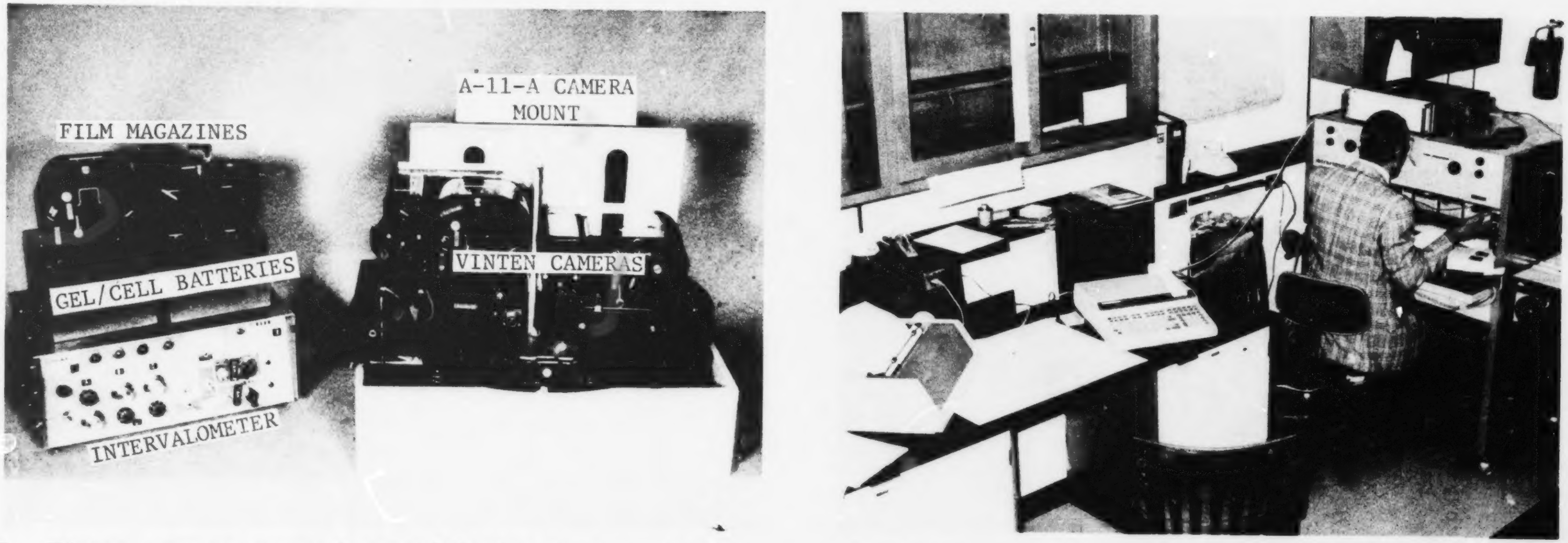

VINTEN CAMERA
RADAR ANTENNA

A. Camera system mounted under a Bell 206B helicopter.

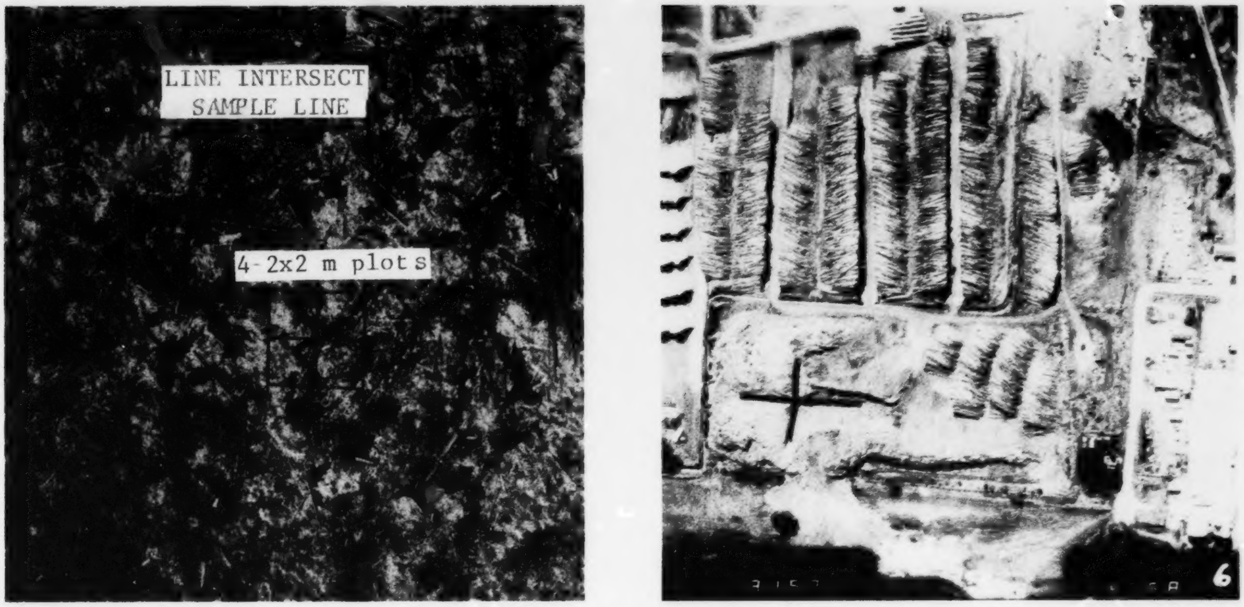
B. Close-up of the aerial cameras and radar antenna mounted as in A.


FILM MAGAZINES
GEL/CELL BATTERIES
INTERVALOMETER
A-11-A CAMERA MOUNT
VINTEN CAMERAS

C. Vinten cameras mounted on modified A-11-A mount for use in fixed-wing aircraft.

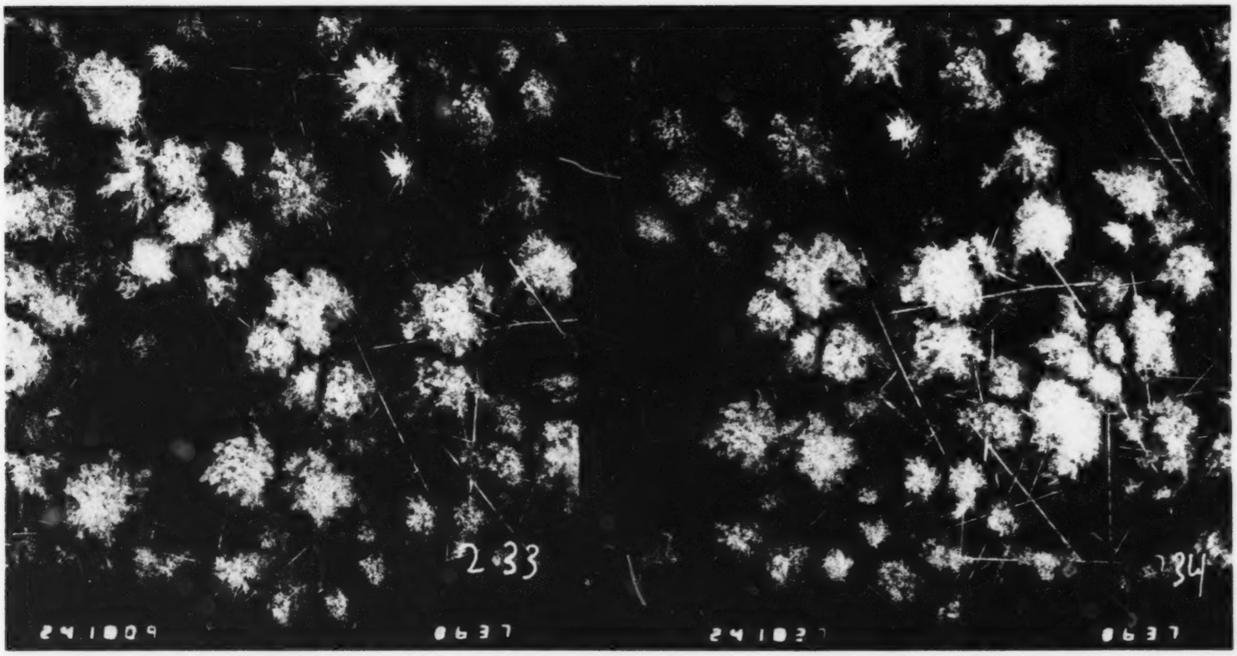
D. Interpretation system: Zeiss-Jena Interpretoskop interfaced to an HP-9825A desk-top computer.

Figure 1. NFRC camera and interpretation system.


LINE INTERSECT
SAMPLE LINE
4-2x2 m plots
6

A. Estimation of logging residues and forest regeneration. (Enlarged scale 1~280)

B. Estimation of wood pile volumes. (Enlarged scale 1~1400)


2·33
234
24 1009
0637
24 1037
0637

C. Estimation of timber volumes. (Enlarged scale 1~ 450)

Figure 2. Examples of applications of large-scale aerial photographs.

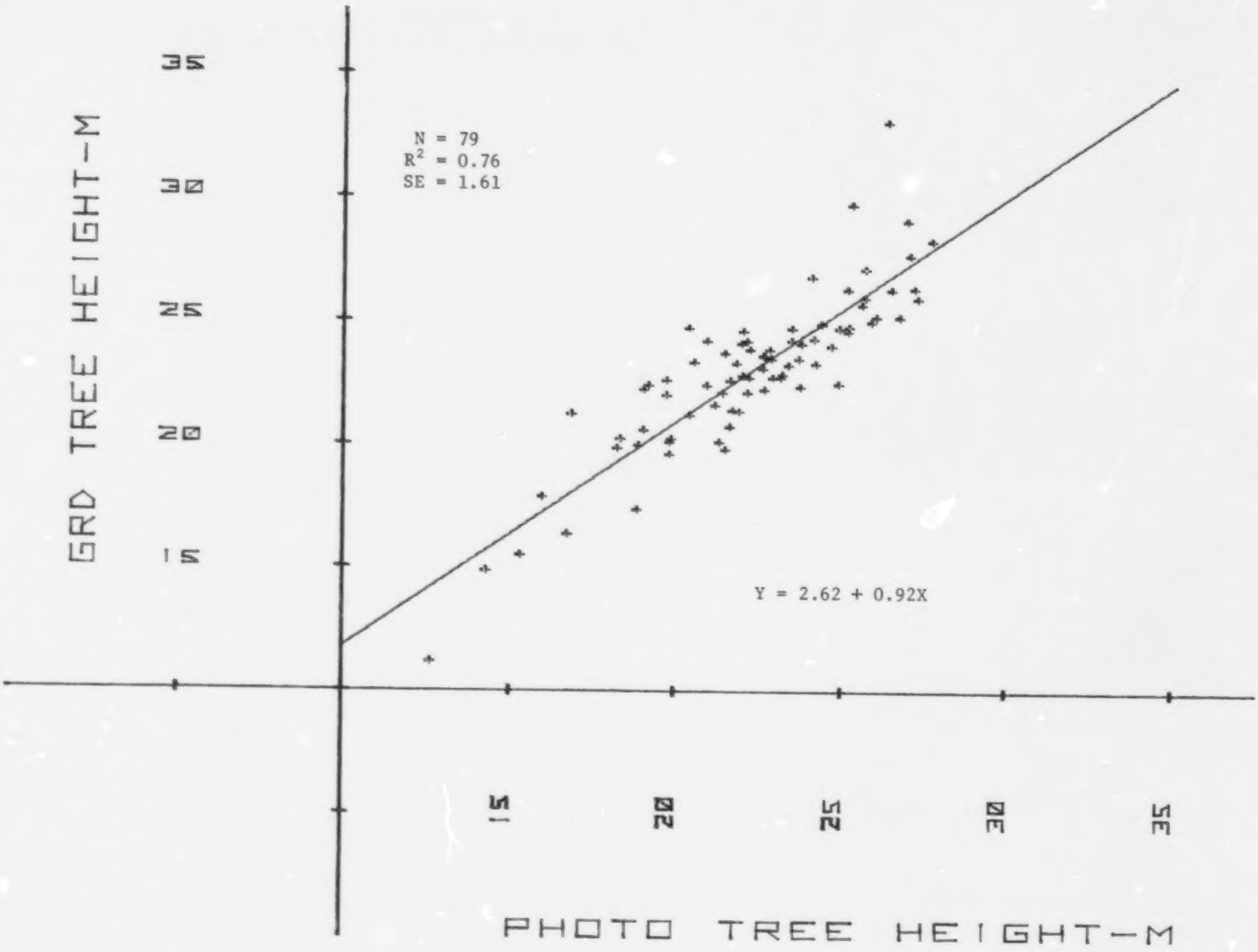


Figure 3. Uncalibrated photo and ground tree heights (m).

APPLICATION OF LARGE-SCALE FIXED-BASE AERIAL PHOTOGRAPHY WITH HELICOPTERS TO FOREST INVENTORY IN B.C.

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ABSTRACT

The fixed-base photographic system described in this paper was developed by the Inventory Branch of the Ministry of Forests, Government of British Columbia, for forest stand classification and sampling. The system consists of twin Hasselblad MK70 70-mm cameras mounted a fixed distance apart on an aerial camera platform attached to the tie-down (jack points) of the helicopter fuselage.

Large-scale stereo pictures are used to identify the species composition of forest stands and to obtain individual tree and stand measurements such as tree height, crown width, number of stems, and crown closure.

An example of the application of the system in British Columbia is given together with the relevant statistical analysis that demonstrates the accuracy of the methodology.

INTRODUCTION

The use of ultralarge-scale photography in recent years has found a well-established position in forestry work and other resource-related disciplines. Two basic methods of photography exist: sequential and fixed base. The latter was developed by the Inventory Branch of the British Columbia Forest Service in the late 1960's. The advantages of fixed-base over sequential photography are that errors due to differential tip and tilt are practically eliminated and the flying height does not vary for the stereo pair. (Edwards and Waelti 1972, Rhody 1977).

In British Columbia, qualitative and quantitative estimates of forest stands combined with multistage sampling are being obtained through detailed interpretation and photogrammetric measurements.

METHODS AND EQUIPMENT

Present equipment comprises Hasselblad Mk70 cameras fitted with reseau glass plates and matched 100-mm f3.5 Zeiss Mk Planar or 60-mm f5.6 Zeiss Mk Biogon lenses. The two cameras are placed and levelled on the airborne camera platform mounted to the tie-down of the helicopter fuselage.

The camera platform, built of aluminum 6061-T6, has a length of 7.25 m and a weight of 67 kg. The distance between the two cameras is 6.1 m. The maximum air speed with the camera platform is 135 mph, and the system is MOT tested and approved.

The requirements of stability in flight and of vibration-free film exposure were guiding principles in the design and construction of the system. The system can be installed within minutes, and a technician operates the cameras using standard Hasselblad equipment.

Film types used will depend on the objective and the desired result of the photography. In mixed stands, because of problems with shadow, normal color film is preferred to color infrared for interpretation and measurement. The working photo is an unenlarged diapositive.

The fixed base (6.1 m) between the cameras is known as the air base, and since the focal length of the lens and the principal points of the photo are known, it is used to determine flying height and photo scale (Finsterwalder and Hofman 1968). Photo base is the air base represented at reduced scale on the picture frame and is the distance between one pair of crosses when a pair of picture frames is viewed in stereo (A reseau grid of 25 crosses 10 mm apart is part of the MK70 camera and is superimposed on each picture frame at the time of exposure).

The relative orientation of the cameras is critical because of the very low ratio between the base length and flying height. (With a base of 6.1 m and a flying height of 100 m, the base to height ratio is 1:16 and the overlap 88.4%).

Measurements are of two types: one point (tree tops only) and two point (tree tops and base). For one-point measurements, a mathematical plane of best fit is used by applying it to three or more ground points. For reasons of speed and simplification, crown width is measured at the widest part.

Preliminary regression equations were developed to predict whole stem volume and dbh from photo measurements of tree heights and maximum crown width. The equations found most suitable are:

$$\text{Ln. Vol. or dbh} = b_0 + b_1\,(\text{Ln. h}) + b_2\,(\text{Ln. CW})$$

$$\text{Vol. or dbh} = b_1\,(1 - e^{b_2(h^{b_3})})\;1^{(b_4 CW)}$$

So far, 6470 trees have been identified and used to develop regressions for various species within recognized forest inventory zones.

LARGE-SCALE PHOTO MISSIONS

Helicopters are preferred over fixed-wing aircraft for large-scale photography because the helicopter can land in small remote spots, can hover over a particular site so that a close visual examination of the area to be photographed can be made, and are better suited to mountainous terrain and changeable weather than fixed-wing aircraft.

The flight path and strip or spots to be photographed are marked on aerial photographs of the area, which then are used for navigation. Camera alignment is checked before each photo mission by photographing a target course of known dimensions.

INTERPRETATION AND MEASUREMENTS

In forest inventory, the large-scale stereo pairs are used for:

1. the interpretation of tree species and indicators of tree disease and decadence and for the determination of species composition and crown closure;
2. the measurement of tree variables such as height and crown dimensions, which are essential for the derivation of diameter and volume equations (Kippen and Sayn-Wittgenstein 1964, Aldred and Sayn-Wittgenstein 1972). The instruments used to obtain these measurements include parallax bars and precision stereo plotters (a Wild A-40 Autograph and a Zeiss/Jena Topocart);
3. residue studies. After comparison with ground measurements, line intersect methods were found to be adequate for the assessment of total residue volume in cut-over and windfall areas. Adequacy depends to some extent upon the quality and the scale of the photographs (Muraro 1970, Van Wagner 1968);
4. regeneration surveys. To obtain a reasonably accurate estimate of restocking and distribution of established trees, large-scale photos combined with ground samples can be applied successfully; and
5. for other uses. The Inventory Branch has flown photo missions for a variety of agencies. These missions include large-scale photography of dikes on the Fraser River and of bridge sites and studies in stream bank protection.

TEST CASE OF THE APPLICATION OF LARGE-SCALE PHOTOGRAPHY TO FOREST INVENTORY

To test the accuracy of the system, four samples are used to compare photo with ground measurements. The selected site is more difficult than is normal. Black-and-white photography was used. The forest stand is a mixture of Pseudotsuga menzeisii (F) and Tsuga heterophylla (H) with a heavy understory of Thuja plicata (C) and Abies balsamea (Bb). The mean age of the stand is 35 years and the mean height 22 m. The sample size is 0.05 ha. All trees 4.8 cm dbh and over were measured on the ground. The average number of trees 4.8 cm dbh and over is 1780 trees/ha. On the ground, 40 dominant and codominant trees were measured for height.

Regression equations developed in the past were used to predict dbh and whole stem volume. The regression coefficients (b_0, b_1, b_2 are only applicable to the forest inventory zone in which the samples are located (Table 1).

RESULTS

1. Tree count

Due to the heavy understory of trees in the 4.8 cm to 12.5 cm dbh classes, a relatively large number of trees were not identified on the photos. The missed trees contribute very little to the total volume and the basal area of the stand.

2. Trees missed by diameter classes

Diameter class	Trees missed	% of trees missed
4.8 cm +	82 trees out of 356 trees	51.12
7.5 cm +	94 trees out of 279 trees	33.69
12.5 cm +	25 trees out of 193 trees	12.95
17.5 cm +	2 trees out of 135 trees	1.48

3. Species identification

All trees within each sample were correctly identified.

4. Tree height measurements

The average difference between photo and ground measured tree heights was 0.9% using a mathematical plane of best fit.

5. Dbh calculations

Dbh for identified trees was calculated using the logarithmic dbh equation:

$$\text{Ln. dbh} = b_0 + b_1 (\text{Ln. ht.}) + b_2 (\text{Ln. CW}) \quad \text{Table 1}$$

A comparison of the mean dbh for trees identified on the photo with that of the same trees measured on the ground is as follows:

Sample no.	Ground	Photo	% difference
1	23.4 cm	21.6 cm	-7.7
2	24.3 cm	22.9 cm	-5.9
3	23.2 cm	23.2 cm	0.0
4	22.5 cm	22.6 cm	+0.4
Total	23.35 cm	22.57 cm	-3.34

6. Basal area

The calculated basal area in m^2 obtained from photo measurements compared with that in m^2 from ground measured dbh is given in Table 2. Due to missed trees in the understory, the differences for trees of diameter class 4.8 cm +, 7.5 cm +, and 12.5 cm + are -17.89%, -15.91%, and -8.91%, respectively.

7. Whole stem volume

Whole stem volume for each identified tree was calculated using the volume regression coefficient given in Table 1. The figures for each sample are given in Table 3. The differences in volume for diameter classes 4.8 cm +, 7.5 cm +, and 12.5 cm + are -11.7%, -10.52%, and -6.97%, respectively.

A representation of the ground cover as seen on the photo is represented for Sample No. 1 in Figure 1. The tree positions correspond to those on the ground.

A statistical analysis of the results for basal area and whole stem volume is given in Table 4 and 5.

There is no significant difference between the means of ground and photo basal area and between ground and photo volume for the 7.5 cm + and 12.5 cm + dbh classes. There is no significant difference between the variances of the two means (basal area and volume) at the 1% and 5% levels. The mean aggregate difference is not significant at $P = 0.05$. These statistics show, therefore, that measurements of volume and basal area from large-scale photos of major portions of stands can predict the same measurements made on the ground.

SUMMARY

In British Columbia, large-scale photography for forest inventory is operational, and plans exist for continuous upgrading and testing of new applications and methodologies. The analysis of tests carried out in the past shows the following:

1. Tree heights and crown dimensions can be measured with at least the same precision as on the ground.
2. Workable single tree volume and diameter regressions based on photo height and crown width for the commercial species in British Columbia can be developed.
3. Further research and development is required, especially in the integration of large scale photography with ground measurements and with aerial photo interpretation.

Table 1. Logarithmic dbh and volume regression

Species		b_o	b_1	b_2	N	R^2	SE
F	dbh	- 0.267194	+ 0.950855	+ 0.388542	179	0.734	3.152
	vol.	-11.193647	+ 3.031370	+ 0.684477	179	0.777	9.764
H	dbh	- 0.115860	+ 0.807970	+ 0.472838	393	0.913	3.073
	vol.	-10.447733	+ 2.575773	+ 0.986864	393	0.930	0.252
C	dbh	+ 0.166671	+ 0.872735	+ 0.272925	305	0.695	3.122
	vol.	- 9.026332	+ 2.468696	+ 0.483954	350	0.804	5.057
B	dbh	- 0.058084	+ 1.027759	+ 0.235971	409	0.881	7.984
	vol.	-10.550641	+ 3.066901	+ 0.386614	409	0.931	0.891

Table 2. Basal area comparison in m^2/ha

	Ground			Photo			% difference*		
SAMPLE	4.8cm+	7.5cm+	12.5cm+	4.8cm+	7.5cm+	12.5cm+	4.8cm+	7.5cm+	12.5cm+
1	43.09	41.77	37.67	30.15	30.15	30.15	-30.03	-27.82	-19.96
2	50.03	48.95	44.06	39.35	39.35	39.35	-21.35	-19.61	-10.69
3	45.07	43.99	41.85	43.16	43.16	42.63	- 4.24	- 1.89	+ 1.86
4	43.71	42.92	39.80	36.70	36.70	36.70	-16.04	-14.49	- 7.79
MEAN	45.47	44.41	40.84	37.34	37.34	37.21	-17.88	-15.92	- 8.89

* % difference as compared to ground measurement.

Table 3. Whole stem volume in m^3/ha

	Ground			Photo			% difference*		
SAMPLE	4.8cm+	7.5cm+	12.5cm+	4.8cm+	7.5cm+	12.5cm+	4.8cm+	7.5cm+	12.5cm+
1	344.37	338.41	316.21	260.40	260.40	260.40	-24.38	-23.05	-17.65
2	377.91	372.68	358.39	325.00	325.00	323.00	-14.00	-12.79	- 9.87
3	390.47	386.16	374.84	371.40	371.40	371.40	- 4.88	- 3.82	- 0.92
4	325.21	321.69	307.53	312.80	312.80	309.00	- 3.82	- 2.76	+ 0.48
MEAN	359.49	354.73	339.24	317.40	317.40	315.59	-11.71	-10.52	- 6.97

* % difference as compared to ground measurement.

Table 4. Statistical comparison of basal area-ground vs photo

	7.5 cm +			12.5 cm +		
	BA G	BA Ph	Difference	BA G	BA Ph	Difference
Σ	177.64	149.36	-28.28	163.36	148.84	-14.52
N	4	4		4	4	
MEAN	44.41	37.34	- 7.07	40.84	37.21	- 3.63
V	9.96	30.01	22.21	8.05	27.77	13.52
SD	3.16	5.48	4.71	2.84	5.27	3.68
SED	1.58	1.17	2.36	1.42	2.63	1.84
F	3.013			3.449		
t.05	2.35			2.35		
t	2.237			1.213		

Table 5. Statistical comparison of volume-ground vs photo

	7.5 cm +			12.5 cm +		
	Vol. G	Vol. Ph	Difference	Vol. G	Vol. Ph	Difference
$\sum$	1418.9	1269.6	-149.3	1356.96	1262.36	-94.60
N	4	4		4	4	
MEAN	354.73	317.40	-37.33	339.24	315.59	-23.65
V	894.07	2081.31	1027.24	1058.89	2389.31	714.64
SD	29.90	45.62	32.05	32.54	48.88	26.73
SED	14.95	22.81	16.03	16.27	24.44	13.37
F	2.328			2.256		
t.05	2.35			2.35		
t	1.369			0.85		

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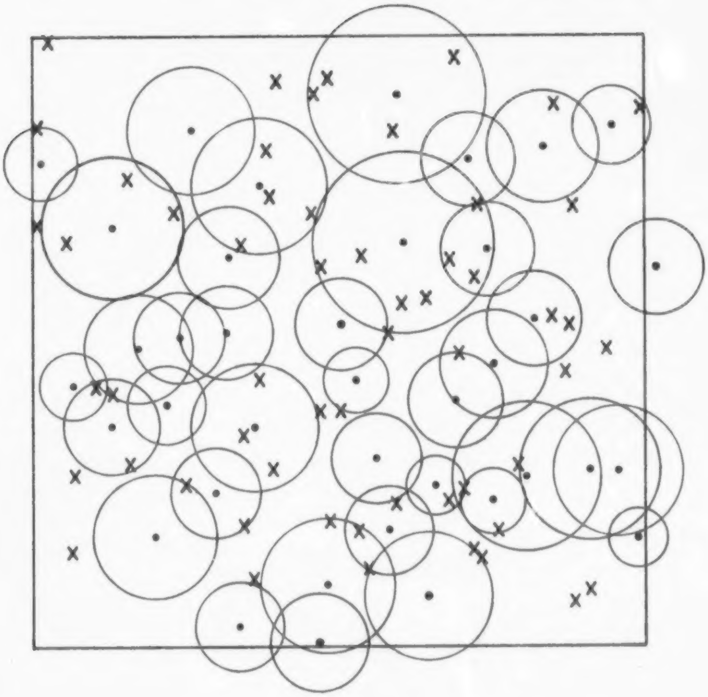

Original photo scale 1:15 700

Area 500 m^2

- • Trees identified on photo
- x Trees missed or not seen on photo
- ○ Maximum Crown area

Figure 1. Sample No. 1, tree and crown positions.

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A TEST OF SMALL-SCALE AERIAL PHOTO SUSCEPTIBILITY RATINGS FOR THE SOUTHERN PINE BEETLE IN EAST TEXAS[1]

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ABSTRACT

Discriminant analysis of infested and noninfested sample data gave a predictive model for susceptibility to southern pine beetle attack. Parameters used were host basal area, average height, and topographic position. A Chi-square test of predicted results against independent attack data was significant at the 95% level.

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INTRODUCTION

The southern pine beetle (Dendroctonous frontalis Zimm.) is the single most destructive forest pest in East Texas. The population levels of southern pine beetle (SPB) fluctuate periodically. During this century, serious epidemics have occurred in 1920, 1949-1955, 1965-1968, and 1972-1977 (Weitzman 1975). During the 1976 SPB season, 11,000 infested areas were reported by the Texas Forest Service (1978). Beetle population variation results partly from weather influences (Kroll and Reeves 1978), but stand susceptibility undoubtedly plays a significant part in successful SPB colony establishment (Hedden 1978). Promotion of stand resistance through proper management appears to be a viable method for SPB damage control (Coster 1977). A number of researchers have suggested that stand conditions influence the susceptibility of host timber stands to SPB attack and colonization (Lorio 1968, Lorio and Bennett 1974, Leuschner et al. 1977).

For the successful implementation of a susceptibility rating system, two requirements must be met, accuracy and ease of use. To have both of these, it was decided that some sort of aerial photo stand classification system would be attempted.

METHODS

During the period 1975-1978, 898 stands of loblolly pine were sampled in Nacogdoches, Angelina, and San Augustine counties, Texas. These stands were equally divided between SPB-infested and uninfested stands. Uninfested samples were randomly located, and infested samples were located in areas noted to be SPB-infested by the Texas Forest Service (1978).

Discriminant analysis of data showed that stand variables could be used to predict which areas were more susceptible to SPB attack and subsequent colonization. Use of variables which were discernible from small-scale (1:60 000) aerial photography appeared to be the most feasible method of analysis. Discriminant analysis of data using classes of pine basal area, average pine height, and topographic position gave correct classification of infested versus noninfested sites with greater than 70% accuracy.

To test the predictive model, nearby areas were classified into classes of pine basal area, pine average height, and topographic position using existing aerial photographs made during 1972-1976. The classification of susceptibility according to the discriminant model was then compared to existing records of more than 500 SPB attacks during the 1973-1977 period (Texas Forest Service 1978).

RESULTS

The discriminant function that was used was:

$$C = -5.9 + 0.65\ H + 1.02\ B + 0.56\ T$$

where: C is the classification value,
-5.9 is a constant,
H is average height to 25-foot classes,
B is basal area to 40 square-foot per acre classes, and
T is a code number for topographic position, where:
1 denotes swamp or bottomland,
2 denotes sideslopes, and
3 denotes ridgetops.

Comparison of actual SPB infestations in host stands versus the predicted infestation or noninfestation (A positive score on the discriminant value predicted infestation.) With a Chi-square test showed that the chance that the susceptibility rating model did not predict SPB infestation locations was less than 2%.

It was concluded that classification of susceptibility of loblolly pine stands to SPB infestation from use of small-scale aerial photographs is practical in East Texas.

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NESTED CLASSIFICATION:
A FIVE-STAGE NESTED SAMPLING DESIGN

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ABSTRACT

The five-stage sampling design is generalized from the three-stage nested sampling design presented in standard texts on experimental designs. This paper can be considered a supplement to these books. The paper demonstrates the structural model and the necessary calculations to be performed for easy adoption in a computer algorithm. The required sums of squares are derived. Without derivation, the standard errors, required for testing observed differences, are presented. An example of the application of the five-stage nested classification is included as well.

INTRODUCTION

Most books on experimental designs do not go beyond a three-stage nested sampling design (Mendenhall 1968, Steel and Torrie 1960, Snedecor and Cochran 1967). Higher-order nested classifications do not seem to occur frequently. Winer (1971) treats incomplete nested experiments at higher stages, but texts dealing with nested sampling designs at order four or higher seem few and far between. Still, the five-stage nested sampling experiment does occur and will be presented below. First, the three-stage nested design, discussed in standard texts, will be presented. The higher stages can be generalized from the three-stage design which itself is a trivial extension of the completely randomised design. The case will be restricted to random effect models, and equal replications within each stage are assumed.

The general model for the three-stage nested sampling design is as follows:

$$X_{ijk} = \mu+\alpha_i+\beta_{ij}+\gamma_{ijk}$$

$$i = 1\ldots a$$
$$j = 1\ldots b$$
$$k = 1\ldots c$$
$$\alpha_i = N(0,\sigma_A^2)$$
$$\beta_{ij} = N(0,\sigma_B^2)$$
$$\gamma_{ijk} = N(0,\sigma_C^2)$$

The required degrees of freedom and sums of squares as well as the estimated mean squares are presented below.

ANOVA

SV	df	SS	E(MS)
A	a-1	SS(A)	$\sigma_C^2+c\sigma_B^2+bc\sigma_A^2$
B/A	a(b-1)	SS(B/A)	$\sigma_C^2+c\sigma_B^2$
C/B	ab(c-1)	SS(C/B)	σ_C^2
Total	abc-1	SS(C)=SS(Total)	

The sums of squares are calculated as follows:

$$CF=\frac{\left(\sum\sum\sum_{ijk}^{abc} X_{ijk}\right)^2}{abc}$$

$$SS(A)=\sum_{i}^{a}\frac{\left(\sum\sum_{jk}^{bc} X_{ijk}\right)^2}{bc}-CF$$

$$SS(B)=\sum\sum_{ij}^{ab}\frac{\left(\sum_{k}^{c} X_{ijk}\right)^2}{c}-CF$$

$$SS(C)=SS(Total)=\sum\sum\sum_{ijk}^{abc} X_{ijk}^2-CF$$

$$SS(C/B)=SS(C)-\{SS(A)+SS(B/A)\}$$

$$SS(B/A)=SS(B)-SS(A)$$

then: $SS(C/B)=SS(C)-SS(A)-SS(B)+SS(A)$
$=SS(C)-SS(B)$

This is how the subsample sum of squares calculations are usually presented. Algebraically, they are as shown below; it should be noted that the correction term (CF) disappears at every level of subsampling and is retained only for the first stage and the total about the overall mean.

$$SS(C/B)=\sum\sum\sum_{ijk}^{abc} X_{ijk}^2-\sum\sum_{ij}^{ab}\frac{\left(\sum_{k}^{c} X_{ijk}\right)^2}{c}$$

$$SS(B/A)=\sum\sum_{ij}^{ab}\frac{\left(\sum_{k}^{c} X_{ijk}\right)^2}{c}-\sum_{i}^{a}\frac{\left(\sum\sum_{jk}^{bc} X_{ijk}\right)^2}{bc}$$

The five-stage nested design is extrapolated from the three-stage design and is presented below in a generalized form. The results of an actual sample survey will be given. The model and calculations for the four-stage design can be interpolated and designs with more than five stages can be extrapolated from the five-stage presentation.

The structural model of the five-stage sampling design is:

$$X_{ijklm}=\mu+\alpha_i+\beta_{ij}+\gamma_{ijk}+\delta_{ijkl}+\varepsilon_{ijklm}$$

$i=1\ldots a$
$j=1\ldots b$
$k=1\ldots c$
$l=1\ldots d$
$m=1\ldots e$

$\alpha_i=N(0,\sigma_A^2)$
$\beta_{ij}=N(0,\sigma_B^2)$
$\gamma_{ijk}=N(0,\sigma_C^2)$
$\delta_{ijkl}=N(0,\sigma_D^2)$
$\varepsilon_{ijklm}=N(0,\sigma_E^2)$

The necessary sums of squares and degrees of freedom for this design are presented below, again with the estimated mean squares. It should be noted that the description of the sources of variation, as given in standard texts, is incomplete. The complete description is therefore presented well, although the reason for the shorter notation will become apparent shortly.

ANOVA

SV	SV	df	SS	
A	A	a-1	SS(A)	$\sigma_E^2+e\sigma_D^2+de\sigma_C^2+cde\sigma_B^2+bcde\sigma_A^2$
B/A	B/A	a(b-1)	SS(B/A)	$\sigma_E^2+e\sigma_D^2+de\sigma_C^2+cde\sigma_B^2$
C/B/A	C/B	ab(c-1)	SS(C/B)	$\sigma_E^2+e\sigma_D^2+de\sigma_C^2$
D/C/B/A	D/C	abc(d-1)	SS(D/C)	$\sigma_E^2+e\sigma_D^2$
E/D/C/B/A	E/D	abcd(e-1)	SS(E/D)	σ_E^2
	Total	abcde-1	SS(E)	

The calculation of the following sums of squares is required. With the exception of SS(A) and SS(E)=SS(Total), these do not form part of the ANOVA table, but are required for the calculation of the subsample sums of squares.

$$CF=\frac{\left(\mathop{\sum\sum\sum\sum\sum}\limits_{ijklm}^{abcde} X_{ijklm}\right)^2}{abcde}$$

$$SS(A)=\mathop{\sum}\limits_{i}^{a}\frac{\left(\mathop{\sum\sum\sum\sum}\limits_{jklm}^{bcde} X_{ijklm}\right)^2}{bcde}-CF$$

$$SS(B)=\mathop{\sum\sum}\limits_{ij}^{ab}\frac{\left(\mathop{\sum\sum\sum}\limits_{klm}^{cde} X_{ijklm}\right)^2}{cde}-CF$$

$$SS(C)=\mathop{\sum\sum\sum}\limits_{ijk}^{abc}\frac{\left(\mathop{\sum\sum}\limits_{lm}^{de} X_{ijklm}\right)^2}{de}-CF$$

$$SS(D)=\mathop{\sum\sum\sum\sum}\limits_{ijkl}^{abcd}\frac{\left(\mathop{\sum}\limits_{m}^{e} X_{ijklm}\right)^2}{e}-CF$$

$$SS(E)=SS(Total)=\mathop{\sum\sum\sum\sum\sum}\limits_{ijklm}^{abcde} X^2_{ijklm}-CF$$

The necessary sums of squares at the various stages of subsampling are obtained as follows:

SS(E/D) = SS(E) - [SS(A) + SS(B/A)
+ SS(C/B) + SS(D/C)]
SS(D/C) = SS(D) - [SS(A) + SS(B/A)
+ SS(C/B)]
SS(C/B) = SS(C) - [SS(A) + SS(B/A)]
SS(B/A) = SS(B) - SS(A)

From these statements, the following results are obtained:

SS(C/B) = SS(C) - SS(A) - SS(B)
+ SS(A) = SS(C) - SS(B)
SS(D/C) = SS(D) - SS(A) - SS(B)
+ SS(A) - SS(C) + SS(B)
= SS(D) - SS(C)
SS(E/D) = SS(E) - SS(A) - SS(B)
+ SS(A) - SS(C) + SS(B) +
- SS(D) + SS(C)
= SS(E) - SS(D)

It is from these results that the shorter notation for the sources of variation originate. Algebraically, these sums of squares are as follows, and again it should be noted that the correction terms have disappeared:

$$SS(B/A)=\mathop{\sum\sum}\limits_{ij}^{ab}\frac{\left(\mathop{\sum\sum\sum}\limits_{klm}^{cde} X_{ijklm}\right)^2}{cde}-\mathop{\sum}\limits_{i}^{a}\frac{\left(\mathop{\sum\sum\sum\sum}\limits_{jklm}^{bcde} X_{ijklm}\right)^2}{bcde}$$

$$SS(C/B)=\mathop{\sum\sum\sum}\limits_{ijk}^{abc}\frac{\left(\mathop{\sum\sum}\limits_{lm}^{de} X_{ijklm}\right)^2}{de}-\mathop{\sum\sum}\limits_{ij}^{ab}\frac{\left(\mathop{\sum\sum\sum}\limits_{klm}^{cde} X_{ijklm}\right)^2}{cde}$$

$$SS(D/C)=\mathop{\sum\sum\sum\sum}\limits_{ijkl}^{abcd}\frac{\left(\mathop{\sum}\limits_{m}^{e} X_{ijklm}\right)^2}{e}-\mathop{\sum\sum\sum}\limits_{ijk}^{abc}\frac{\left(\mathop{\sum\sum}\limits_{lm}^{de} X_{ijklm}\right)^2}{de}$$

$$SS(E/D)=\mathop{\sum\sum\sum\sum\sum}\limits_{ijklm}^{abcde} X^2_{ijklm}-\mathop{\sum\sum\sum\sum}\limits_{ijkl}^{abcd}\frac{\left(\mathop{\sum}\limits_{m}^{e} X_{ijklm}\right)^2}{e}$$

If MS denotes the mean square obtained by dividing the SS by its corresponding degrees of freedom, an MS at any level becomes the denominator to test for differences between means at the previous level. For example, to test whether differences between means of the level of C/B are significant, the F test to be performed is:

$$F = \frac{MS(C/B)}{MS(D/C)}$$

with ab(c-1) and abc(d-1) degrees of freedom. This also gives an indication of how the standard errors, which may be required, are obtained. While theoretical considerations are considerable, for practical purposes the following table presents the standard errors with their corresponding degrees of freedom.

SV	Standard Error	Degrees of Freedom
A	$s_{\bar{a}} = \sqrt{\frac{MS(B/A)}{b}}$	a(b-1)
B/A	$s_{\overline{a/b}} = \sqrt{\frac{MS(C/B)}{bc}}$	ab(c-1)
C/B	$s_{\overline{c/b}} = \sqrt{\frac{MS(D/C)}{bcd}}$	abc(d-1)
D/C	$s_{\overline{d/c}} = \sqrt{\frac{MS(E/D)}{bcde}}$	abcd(e-1)

An example of a five-stage nested sampling design is provided by Navratil (unpublished) which, in fact, provided the necessity for the design and the computer program. The density of stomata on the leaves of trembling aspen in the neighborhood of Sudbury was measured. Eight areas were selected in the region; in each of these areas three clones were selected and within each clone, three trees. Three leaves per tree were selected, and the stomata density was determined from three segments of each leaf.

Using the structural model presented above and the calculations as described, the following results were obtained:

Hierarchal analysis of variance

SV	df	SS	MS	VR	P
Areas	7	859.0	122.7	<1	>0.10
Clones/area	16	2354.8	147.2	7.2	≪0.005
Trees/clone	48	982.2	20.5	2.8	≪0.005
Leaves/tree	144	1038.9	7.2	1.4	≃0.005
Stomata/leaf	432	2204.7	5.1		
Total	647	7439.6			

As indicated above, the F tests are the variance ratios of two successive sources of variation. Because of the successively higher degrees of freedom, small variance ratios are declared significant. The study did not require calculations of standard errors.

The model has been presented to supplement the treatment given nested classification in standard texts on experimental designs. It should also demonstrate the systematic manner in which the computer program has been written and which may be needed in the absence of a library subroutine.

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NEW TECHNIQUES IN PROVINCIAL FOREST INVENTORY

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PROVINCIAL FOREST INVENTORIES: TECHNIQUES AND DEVELOPMENT

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ABSTRACT

Data on Canada's forest resources are obtained almost exclusively from provincial forest inventories. Developed over the last 35 years, the procedures used in these inventories are quite similar. One exception is the inventory used in Ontario, which relies on the measurement of stand parameters applied to yield tables for the estimation of volume and other attributes. Other minor differences are found in the inventories of Newfoundland and Nova Scotia.

Until recently, the only major change in procedures was the introduction of point sampling. Now, changes are occurring more rapidly. This results from the availability of more sophisticated sampling designs (3P, SPR), improved technology (computers and computerized systems, remote sensing), and the need to reduce the cost of fieldwork.

In the future, changes are likely to continue: more detailed data will be necessary for intensive forest managment, new types of data (biomass) will be requested, and new technology (LANDSAT) will become operational.

INTRODUCTION

Remote sensing is an important part of forest inventory; however, it is only one of many parts which the planner must consider in developing an effective inventory. The remote sensing specialist often forgets that. This paper describes all the different parts of a typical forest inventory and how they fit together. Following a discussion of differences between inventories in Canada, recent developments and advances are presented, and an educated guess is made of future trends.

A discussion of provincial forest inventories is really a discussion of Canadian forest inventories. The primary reason is that 83% of the inventoried forest land in Canada belongs to the provinces (Bowen 1978). This land is either inventoried by the provinces or by leaseholders to meet provincial requirements. Inventory techniques on the remaining land (federal 11% and private 6%) do not differ significantly from provincial techniques.

Inventory procedures vary, depending on a number of factors which include the extent of coverage and the detail and type of information required. The great majority of provincial inventories, however, serve one purpose: to obtain estimates of areas and wood volumes by different classes for extensive areas, with sufficient detail for management and planning. They are not designed to monitor changes. Such inventories are called management and regional inventories and are the focus of this paper.

STANDARD INVENTORY TECHNIQUES

Inventories (management and regional) consist of a sequence of common tasks or steps. This paper provides an outline of these steps to serve as a point of reference for subsequent discussions. More detailed information is given by Bonnor (1978).

The first step is to develop a forest and land area classification system whereby subsequent estimates are compiled. Classifiers include ownership, administrative category, land class, and forest cover. The last is subdivided into many other classifiers, e.g., stocking, productivity, and forest types.

The second step is to produce base maps of the inventory area. They display only sufficient information (roads, water bodies) to locate forestry information added to the map later.

In the next step, the location and type of forest cover of the entire inventory area are determined. This is where remote sensing comes in. The approach generally used is to obtain aerial photos at medium scales and to interpret them. The interpretation includes a delineation of homogeneous areas and a classificiation of each area according to the classification system.

The photo-interpreted data as well as data on ownership and administrative boundaries are now transferred to the base map. The resulting product, complete with legend, is called a forest map. From this map, the area of each polygon (e.g., a stand) is determined, and a list of areas is produced, ready for summarization according to the classification system.

The forest map provides not only a map of the forest types and their extent but also a framework for subsequent field sampling. Such sampling is necessary to provide detailed information (e.g., volume by species) which cannot be obtained from the standard air photos. Statistical procedures are used to determine the number of sample plots required. Plot locations are then selected on the map, systematically or at random, within the forest types. Often, the plot locations are transferred back to the air photos for easier field location. Field crews go to the specified locations, establish the plots, and obtain the required data. For each tree these include species identification and measurement of dbh. Other data frequently noted are height, age, growth, and quality. Stand data (height, basal area, species composition) as well as soil and terrain characteristics may also be noted.

The main purpose of the field survey is to obtain volume data. The field-plot data (species, dbh, and often tree height) are applied to tree volume equations, and individual tree volumes are calculated. These are then summarized (by species) for each plot, and average volumes per plot or per hectare are calculated for different forest types. Multiplication of the averages with forest type areas gives total estimated volumes.

The final step is to compile and summarize the data (primarily areas and volumes by different classes) and to report the results.

In statistical terms, the inventory procedures described use a stratified random sampling design: air photos are used to identify and map strata (forest cover types), and a field survey is used to obtain detailed estimates (primarily of volume) for each stratum.

SPECIAL INVENTORY TECHNIQUES

Several provincial inventories utilize techniques which differ from those already described. Chief amongst them is the Forest Resource Inventory (FRI) of Ontario. In the FRI, field survey and photo-interpretation data are both used to map forest types. While this poststratification results in better forest typing, the calculation of precision estimates becomes more difficult. Secondly, the number of forest types is limited to 12 major working groups by which estimates are compiled. Thirdly, measurements of stand parameters are made: the stand is the basic unit of measurement and compilation. Fourthly, yield tables (applicable to stands) rather than tree volume tables are used to obtain detailed estimates. Yield tables have the advantage that they provide data on many different attributes, including volume, growth, and basal area, and they can be used to project stand development. There is some evidence, however, that the use of yield tables, stand parameters, and working groups is not compatible with the variety of forest types found in Ontario and that the accuracy of the resulting inventory estimates is insufficient for today's needs.

In most provincial inventories, forest-type areas are obtained from map measurements, usually dot gridding, of the delineated types. In Nova Scotia, a different procedure is used: area estimates of a forest type are obtained by calculating the proportion of field plots which fall in that type and applying this proportion to the total area involved. This procedure is rapid and inexpensive, but it provides only approximate areas and no map of forest-type locations. The Global Inventory in Newfoundland utilizes the same procedures, but forest maps showing forest type boundaries are produced in a separate phase.

RECENT DEVELOPMENTS

The last decade has seen a number of advances in fields affecting forest inventory methodology. These advances are slowly being tested and incorporated into provincial inventories.

In the field of sampling techniques, the recently developed 3P method (Probability Proportional to Prediction) has been applied in Nova Scotia to estimate wood volumes by size and quality classes. Nova Scotia is also planning to use 3P in a multistage forest inventory to replace the current inventory methods. A modified version of the 3P method has also been tested successfully in Saskatchewan and is now being incorporated into the inventory design.

In the field of remote sensing, Ontario has started a reconnaissance inventory of northern forests using LANDSAT imagery. The procedure uses supervised classification of digital LANDSAT data. The results will consist of maps and tables summarizing data by forest types and volume clases. Ontario also plans to use LANDSAT to update results of the standard Forest Resource Inventory.

In Nova Scotia, tests are under way to evaluate the effectiveness of color infrared (CIR) photography in forest inventories. The tests include photos at scales of 1:5 000, 1:10 000, and 1:50 000. The test area is Cape Breton Island, and emphasis is placed on damage detection and the ability to define defoliation classes. Nova Scotia also plans to use LANDSAT imagery to update cut-over areas.

In Alberta, large-scale aerial photography has been successfully tested and incorporated into the basic inventory design.

In the field of mapping, a major problem is the time and cost required to calculate areas of stands and forest types, to update maps, and to convert them to metric units. To solve these problems, the B.C. Forest Service has implemented a computerized mapping system, the Interactive Graphics Display System. The provinces of Ontario and Saskatchewan are also investigating the use of such a system.

FUTURE DEVELOPMENTS

Any changes in forest inventory methodology will depend on changes in data requirements, the need for improved procedures, and the availability of proven technological developments. What changes can we expect in the future?

A major change will result from the need for new kinds of data and for more detailed data. For example, forest biomass data will be required and can be obtained fairly readily via existing inventories. Also, data from other fields, e.g., wildlife and recreation, will be required. Such data will be obtained by means of integrated forest resource inventories. The U.S. Forest Service has been working on this aspect for several years, and several of our provinces are exploring alternatives and implications of such inventories. Finally, more detailed data on changes in the forest resources will be required to determine if they are decreasing and what management practices must be implemented. To obtain such data, different sampling designs, e.g., Sampling with Partial Replacement, must be used.

Computers have been used for many years in the compilation of forest inventory data and are now also being used in mapping, so it is reasonable to assume that computer usage will spread to other fields. For example, the whole process, starting with air photo interpretation and ending with the production of forest maps, could be highly automated.

Further developments in remote sensing can also be expected. For instance, the full potential of existing LANDSAT imagery has not yet been realized, and no-one knows what kind of forestry information can be extracted from the new LANDSAT D. LANDSAT represents a new source of information which, when sufficiently analyzed, can be used with advanced sampling designs (e.g., multistage) to obtain forest resource data more effectively.

DISCUSSION AND CONCLUSION

As previously mentioned, most provinces use the same inventory techniques. The inventories differ, however, in the application of these techniques. One major difference is in the area classification system; no two provincial inventories use the same system. This makes it very difficult to compare the results and to compile the results into a national summary. The standard techniques have also changed with the passage of time; for example, point sampling is now used more than plot sampling in fieldwork.

The special inventory techniques represent early attempts to improve standard techniques or adapt them to meet special requirements. The recent developments are a continuation of these improvements; the examples given are not intended to be exhaustive but to indicate how the inventories are changing.

Future developments are presented with some degree of confidence, based on past and present trends and on a consideration of the status of forestry in Canada. Where are we now, and where are we heading? The basic fact is that we are running out of economically accessible, high-quality wood. In some provinces, the annual harvest even exceeds the annual growth. Much cut-over land, productive and easily accessible, is not sufficiently stocked. These facts are well known, and people are worried about them. What is also well known is that we can do something about it.

Through intensive forest management, we can double the yield of high-quality wood on productive, accessible land. This is where forest inventories come in. To do something about decreasing yields, we need much better data on our forest resources: the data have to be more accurate, more detailed, and more location-specific. Furthermore, inventories have to monitor changes in the forest resources. This is the challenge. I hope we will be ready to meet it.

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CHANGING TECHNOLOGY IN THE SASKATCHEWAN FOREST INVENTORY

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ABSTRACT

The Saskatchewan Forest Inventory consists of maps and estimates of standing timber by species and size classes, within stratifications identified from aerial photographs. Recent technological advances have made it possible to improve both the quality and the method of presentation of inventory data. The process of incorporating some of these changes into the Saskatchewan Forest Inventory will be discussed in three parts.

A. MAPPING:

- increasing use of digital computers in the storage and manipulation of map data.

B. FIELD DATA REQUISITION:

- incorporation of 3P (Probability Proportional to Prediction) sampling techniques into the collection of field data.
- adoption of large-scale photo sampling techniques in the Reconnaissance Forest Zone.

C. DATA PROCESSING:

- increasing flexibility in the selection and presentation of inventory data.
- introduction of growth simulation into the forest inventory.

The present and proposed systems and procedures, as well as future trends in the inventory process, will be discussed in each part.

INTRODUCTION

In order to accept any form of remote sensing as an integral part of the work flow of an inventory, the responsible agency must be prepared to supply the necessary supporting organization and funds. Saskatchewan utilizes remote sensing in the form of vertical aerial photography of various scale ratios in the development and maintenance of an inventory of the forest resource within the boundaries of the Provincial Forest. The supporting agency is the Government of Saskatchewan through the Department of Tourism and Renewable Resources, Forestry Branch. Funding is provided from normal budgetary procedures within provincial departments and, on occasion, from special agreements with the Government of Canada. (Examples of such special agreements are the Canada Land Inventory Program and the recently signed Subsidiary Forest Agreement.)

The Provincial Forest in Saskatchewan is a legal entity, that is, the boundaries are defined in surveying terms and described in a piece of legislation entitled The Forest Act. This area amounts to about 354,585 km^2 or 54% of the total area of Saskatchewan. Primarily due to the twin problems of inaccessibility and remoteness from the market, the majority of the Provincial Forest, about 59%, is considered noncommercial and is classified as the Reconnaissance Forest Zone. The remaining 41% or 144,095 km^2 is classified as the Commercial Forest Zone. It is considered accessible and the forest resource thereon marketable. Within the Commercial Forest Zone, about 55% or 79,250 km^2 is productive land, that is, land that is capable of producing merchantable trees within a reasonable length of time. The present estimate of gross merchantable volume (30 cm stump, 7.62 inside bark, top diameter) is:

Softwoods......	284,194,000 m^3	(59%)
Hardwoods......	200,400,000 m^3	(41%)
Total..........	484,594,000 m^3	(100%)

THE PRESENT SYSTEM

Saskatchewan recently has embarked upon a new forest inventory program entitled Block Inventory. The entire Provincial Forest has been stratified into 10 major regions or blocks, seven in the Commercial Zone and three in the Reconnaissance Zone. The boundaries between blocks are based upon preliminary identification of differences in physiographic and/or vegetation factors. These boundaries will be adjusted as more reliable information becomes available from the Block Inventory program. A very general flow chart of the procedures being used for the program is shown in Figure 1. These procedures can be grouped into three general activities:

A. Mapping
B. Acquisition of Field Data
C. Data Processing

A. Mapping:

The first step in the production of forestry maps is the acquisition of aerial photography. With the introduction of the Block Inventory Program, scale ratios were changed from 1:15 840 to 1:12 500 in the Commercial Forest Zone and from 1:25 000 to 1:50 000 in the Reconnaissance Forest Zone. At present about 53% of the Provincial Forest has been photographed at the new scale ratios, and all new photography is scheduled to be completed by the end of 1986. A photo library of about 155,000 prints is maintained in-house, with all pictures available on a temporary loan basis. Limited capability for print production from available negatives also is maintained.

Interpretation of aerial photographs is done using Zeiss stereoprets with four-power binoculars. Average production amounts to about 16 to 20 km^2 or three and one-half to four and one-half pictures per man-day, with the better interpreters reaching six to seven pictures per man-day. Recognized forest stratifications are illustrated in Figure 2. An example of a forest cover type label is shown in Figure 3.

Forestry base maps have been, and presently are, prepared using radial line triangulation with slotted templates. The flat topography and lack of sufficient survey control necessitate the preparation of new base maps with each block of new or replacement photography. Maps being prepared under the Block Inventory Program are based on the 6° Universal transverse Mercator (UTM) projection, and map boundaries are assigned from the 10,000 m grid. The step-by-step procedures for map preparation are:

1. Determine survey control (supplemented from the National Topographic Series at 1:50 000, as necessary.
2. On each aerial photograph, pick center points, conjugate center points, and pass points; these points provide the link between adjacent photos and flight lines.
3. Transfer the points to template-board material which is directionally stable, and cut radial slots from the center of each template through all conjugate centers, pass points, and survey control points.
4. Lay out the UTM grid on the mapping floor.
5. Plot all survey control on the grid.
6. Bridge among all survey control points with the slotted templates.
7. Transfer and label the adjusted photo point locations to the mapping floor.
8. Transfer the grid and the adjusted photo points to mylar.
9. Using the photo points, which now are common to both the aerial photographs and the base map, transfer the interpreted data from the photos to the mylar.
10. Carry out a color check, that is, visually compare the drafted map with the appropriate aerial photographs and note all corrections to be redrafted.

The completed map is 80 X 80 cm, exclusive of the legend, and depicts an area of 100 km^2. The average cost break-down to produce a complete map of 100 km^2 is:

Aerial Photography	-	$ 412.96
Photo Interpretation	-	604.07
Base Mapping	-	290.90
Drafting	-	463.04
SUBTOTAL		$1,770.97
Supervision	-	225.00
Depreciation of Equipment	-	102.00
SUBTOTAL		$ 327.00
TOTAL COST FOR 100 km^2		$2,097.97

Estimating office space costs at about \$95/m^2 would add about \$115 to the cost per map.

With a 10-year cycle of rephotography it is necessary to incorporate updating procedures into the mapping process. Using in-house equipment consisting of a 70 mm camera with accessories and adequate darkroom facilities, plus access to a twin-engine aircraft, it is anticipated that all disturbances such as harvesting, wildfires, and road building can be updated annually. In addition, Dr. Y. Jim Lee of the Pacific Forest Research Centre is conducting a test using LANDSAT data for illustrating progressive harvesting activities for a portion of the Commercial Forest Zone.

B. Acquisition of Field Data:

In 1977, field tests were carried out to compare various sampling techniques both for estimating the present standing volume and for establishing a network of sample plots for future remeasurement. Techniques tested were:

1. 3P sampling, fixed area base.
2. Point sampling - Basal Area Factor = 40
   = 20
   = 10
3. Point sampling with variable Basal Area Factor for:
   - 4 trees, minimum
   - 5 trees, minimum
4. Point 3P sampling
5. Double sampling with 1:12 500 aerial photographs.

The methods used to collect the field data, coupled with a limited budget, did not allow the inclusion of time trials, although the time requried for each technique was estimated in terms of production per man-day. Although several factors were taken into account, the primary criterion for selecting the most suitable sampling technique was the standard error of mean gross merchantable volume per hectare. The selected technique incorporated the establishment of area plots with sample trees within each plot chosen using 3P (Probability Proportional to Prediction) procedures.

The step-by-step field procedures are as follows:

1. Lay out cruise line on the UTM map.

2. Locate and label the starting point in the field.

3. Compass and chain to the beginning of the sample plot.

4. Label the plot number on a tree near the beginning of the plot.

5. Determine the plot center line 50 m in length.

6. Mark the plot planimeter; note that plot width varies with stand density.

7. Dot tally in 2 cm dbhob (diameter at breast height over bark) classes all stems larger than 7.0 cm.

8. Select sample trees by comparing a local volume table value for each stem with successive values from a random number table.

9. Measure all sample trees for dbhob to 0.1 cm and for total tree height to 0.1 m.

10. Determine the age of one selected sample tree per species.

11. Determine soil texture and drainage from a soil sample (only done by qualified personnel).

12. Record lesser vegetation (only done by qualified personnel).

A usual day's work for a two-person field crew is 10 plots per day. With present staffing and funds, it is anticipated that 3,500 to 4,000 plots will be established annually.

C. Data Processing:

The majority of data porocessing in the Saskatchewan Forest Inventory is done on an IBM 370-158 main-frame computer. Field data is keyed from tally sheets onto magnetic diskettes. This data then is read onto a Remote Job Entry (RJE) station in Prince Albert and transferred 145 km on telephone lines to the main-frame in Saskatoon. The data is edited and compiled in Saskatoon and the results transferred back to the RJE for printing in Prince Albert.

At the present time, new map data is not being stored and processed on the computer. Prior to the production of UTM maps, map areas were determined from dot grid overlays; the area for each identified stratification was determined by counting the dots within that stratification within each map unit. This area summary for each map then was recorded on diskette, transferred to the mainframe in Saskatoon, edited and stored on the master file for the Provincial Forest. Thus the smallest compilable area stored on the area files was one full map unit. If information was required for only a portion of a map, then it was necessary to repeat the dot-counting process for that portion of the map and recompile the area data on a separate computer file.

The field data compiled in the form of stand and stock tables was combined with the area data from the maps to produce stand and stock estimates for each map unit. These estimates then were used by government and industry to calculate allowable annual cut and to prepare operating and management plans.

NEW DIRECTIONS

Recent technological advances coupled with additional funds provided through the recently signed agreement between Canada and Saskatchewan has made it possible for Saskatchewan to improve the quality and efficiency of the forest inventory system.

A. Stem Analysis:

During the next 3 years, 1,500 trees of various species will be sectioned and measured. The resultant data will be used to develop volume-per-tree equations to replace the old tabular values, as well as to develop taper equations for predicting upper stem diameters.

In addition, data from some 8,000 previously measured stem analysis trees will be recompiled for comparison with the new data and for possible inclusion in the tree master files.

B. Age Classification:

In the past, stand ages have not been included in the forest inventory. Starting last winter, the collection of age information in the field was initiated and will continue during the forthcoming three winters. The collection of age data during the winter months has several advantages:

1. Field crews from the summer timber cruising can be carried through the winter, thus reducing staff training and turn-over rates.
2. With the advent of snow-toboggans, remote areas are more accessible via trails, streams, and lakes.
3. Helicopters are more readily available, frequently at lower rates.

The field data then is extrapolated by photo interpreters to similar stands growing on similar sites. Finally, every stand will be assigned an age class, and this information will be stored on the master area files for the map data.

C. Mapping Changes:

Saskatchewan is in the process of semiautomating the dot-counting procedures. The new procedures are as follows:

1. Prepare a dot grid overlay.
2. Place the dot grid overlay on a digitizing table and identify the map coordinates via a stylus and key-board.
3. Identify each dot within each stand.

4. Assign a label to all dots within a stand.

5. Verify the stand label via the key-board.

6. Transfer the completed dot entry to the main-frame via the RJE and establish a master area file, maintaining the location of each dot.

This procedure is expected to be in production in November, 1979. Estimated input time is 15 to 18 hours per complete map.

Recent advances in graphics technology have made it technically feasible to store map data in line format in a computer. Saskatchewan has asked Dr. Roger Tomlinson of Tomlinson Associates to 1. evaluate the present mapping and data handling system; 2. evaluate available computer-assisted mapping systems; and 3. prepare a cost-benefit analysis of viable alternatives.

In addition, Dr. Tomlinson has been asked to examine the practicality of entering forestry data into the computer directly from aerial photographs. With mapping control data also stored in the computer, it then should be possible to go directly from aerial photographs to the computer and then to a plotted map which is rectified for scale.

D. Northern Reconnaissance:

The Reconnaissance Forest Zone in Saskatchewan largely is inaccessible. One of the projects under the agreement between Canada and Saskatchewan is to obtain a reconnaissance-level inventory of this area within 3 years. It is anticipated that a large-scale aerial photography sampling system such as that designed by Dr. A. H. Aldred will be used to obtain that inventory. The work done by Dr. Aldred in cooperation with J. J. Lowe of the Alberta Forest Service is particularly encouraging.

E. Growth Simulation:

In the past, Saskatchewan has not attempted to incorporate forest growth into the inventory; estimates of the standing inventory were based on the latest aerial photography and, as a result, tended to be conservative. With increasing pressure on the wood supply, particularly for the higher-value products which generally require the larger log sizes, it is becoming necessary to be able to predict the probable status of future stands. Accordingly, Dr. D. Williams, with Ried, Collins Forest Resource Consultants, have been asked to:

1. Examine the existing and proposed data base.

2. Evaluate available growth simulation models for compatibility with the data base.

3. Initiate the installation of an appropriate growth simulation modelling system into the forest inventory.

One of the growth simulators they will be examining will be the Compatible System of Growth Simulators under development at the Pacific Forest Research Centre in Victoria.

Input data for the growth simulator will be derived from sample plots established during the Block Inventory Program, with validation and calibration from remeasurement data from previously established permanent sample plots in well-stocked stands.

CONCLUSION

The incorporation of new techniques in mapping and data processing plus the emphasis on the collection of new and additional field data will allow Saskatchewan to develop improved forest management and help meet the increasing demand for forest products.

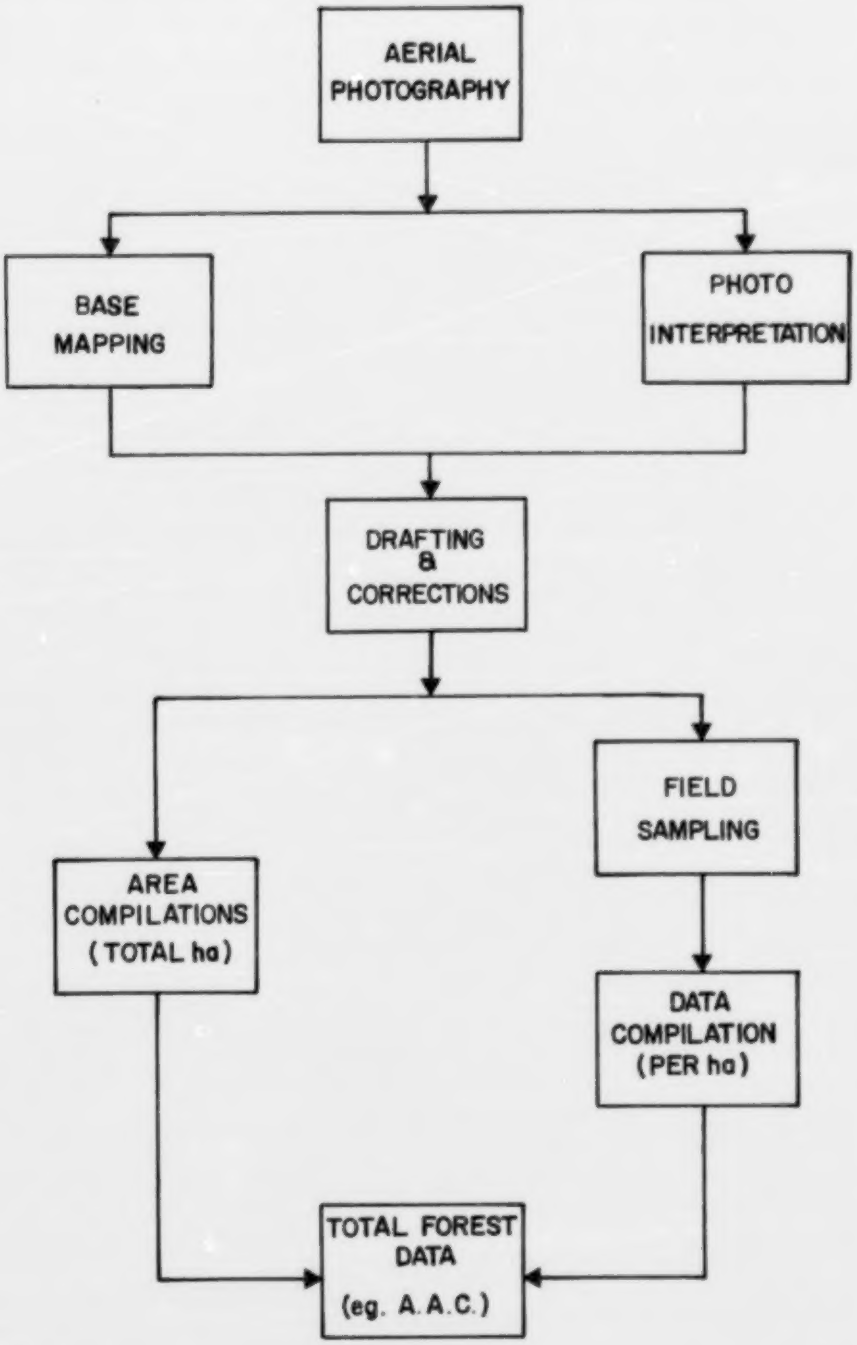
AERIAL PHOTOGRAPHY
BASE MAPPING
PHOTO INTERPRETATION
DRAFTING & CORRECTIONS
FIELD SAMPLING
AREA COMPILATIONS (TOTAL ha)
DATA COMPILATION (PER ha)
TOTAL FOREST DATA (eg. A.A.C.)

Figure I: FLOW CHART OF FOREST INVENTORY PROCEDURES

SPECIES ASSOCIATION

Softwood	(over 75% softwoods by volume)	S
Hardwood	(less than 25% softwoods by volume)	H
Mixedwood	(50% to 75% softwoods by volume)	SH
Mixedwood	(25% to 50% softwoods by volume)	HS

CROWN CLOSURE

10% to 30%	A
30% to 55%	B
55% to 80%	C
80% +	D

HEIGHT

2.5 to 7.5 metres	5
7.5 to 12.5 metres	10
12.5 to 17.5 metres	15
17.5 to 22.5 metres	20
22.5 + metres	25

SPECIES

White Spruce	wS
Black Spruce	bS
Jack Pine	jP
Balsam Fir	bF
Tamarack	tL
Lodgepole Pine	lP
Trembling Aspen	tA
Balsam Poplar	bPo
White Birch	wB
Manitoba Maple	mM
White Elm	wE
Green Ash	gAs
Bur Oak	bO

Each forest sub-division is denoted by a letter, numeral, and letter showing respectively the species association, height, and crown closure.

Burned over	B.O.
Open land	O.P.
Scrub	S.B.
Cut over	C.O.
Fen, bog, open muskeg	✱
Treed muskeg	🌲✱
Treed rock	🌲✓
Clear rock	✓
Clearing	C
Sand	▨
Flooded	☰
Meadow	ɯɯ
Brushland	○

Figure 2: FOREST REFERENCE

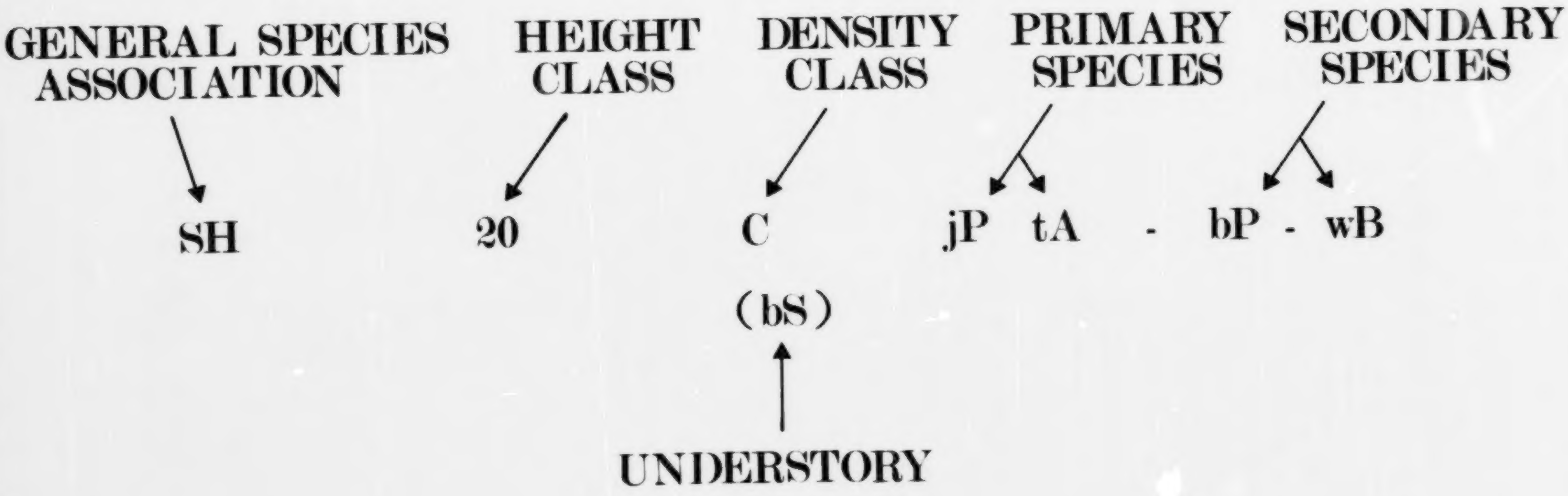
GENERAL SPECIES ASSOCIATION
HEIGHT CLASS
DENSITY CLASS
PRIMARY SPECIES
SECONDARY SPECIES
SH
20
C
jP tA - bP - wB
(bS)
UNDERSTORY

Figure 3: Example of a Forest Cover Type Label – SH20C jP tA bP wB (bS)

THE USE OF MEDIUM- AND LARGE-SCALE PHOTOGRAPHY IN ALBERTA'S TIMBER INVENTORY

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ABSTRACT

Alberta's Phase 3 forest inventory gathers more information than ever, including stand age and site class, through photo interpretation of quality 1:15 000 MIR photography supported by much ground truthing.

Volume sample plots can be measured accurately on the ground and in the office using large-scale photographs. Data from both sources can be handled by one cruise compilation computer system.

INTRODUCTION

Alberta's Department of Energy and Natural Resources has the responsibility for forest inventory. In the widest sense of the term, forest inventory covers more than forest tree cover and its timber content. The department is addressing itself to the need for information on lesser vegetation and site characteristics. Within the context of this seminar, I will discuss only the timber aspect of the inventories.

ALBERTA'S FOREST INVENTORIES

Management inventories of most of Alberta's forest have a 30-year history. Conventional medium-scale photography is the remote sensing tool which has made it possible to map the forest and to stratify it for representative volume samples. It is unfortunate that today's small- and ultrasmall-scale imagery was not available years ago when less intensity was required of the inventory.

The Alberta Forest Service developed and produced in succession the Broad Inventory and then the Detailed Inventory. The Quota Reconnaissance Inventory was a special-purpose variant. Those descriptive names are self-explanatory. Since 1970 we have developed a new inventory which is as compatible with its predecessors as possible, but which has the information and intensity required for the increasing intensity of management. We toyed with the name Very Detailed Inventory but could foresee problems with the Very Very Detailed Inventory, etc., so settled for the name Phase 3.

The situation today is that the Phase 3 Inventory has progressed from design and early production into the full production stage. We have a goal of March 31, 1984, to cover most of the managed forest in the province. The renewal of most timber quotas in 1986 has dictated this timing. The inventory is produced by the Resource Evaluation Branch and the Timber Management Branch, with liaison and control at the branch and division head level. Computer support is mostly in-house at Government Services.

Photography at 1:50 000, or similar scales, is used for base mapping and, increasingly, for the provision of a photo base map. The 1:20 000 base map is enlarged to 1:15 000 for the forest cover maps to fit the preferred photo scale.

After several trials the scale of 1:15 000 was selected for interpretation. We use black-and-white, or modified, IR with strong emphasis on photo quality. At smaller scales such as 1:20 000, we cannot see the single tree detail required for describing the stand structure. At scales larger than 1:15 000 in our timber, we gain little more information but lose the synoptic view and greatly increase problems of cost and handling. One management unit is being tried with true colour. The interpreters appear to like the product, especially for species identification, but no final conclusions have been drawn, and we are aware of the increased cost and reproduction problems.

The core of the inventory is photo interpretation. The interpreters use a minimum stand size of about 10 ha (20 acre) and describe the stand as to density, height, and species composition. Height classes are 6 m (20 ft.). Because most stands are of fire origin we are able to assign 10-year age classes, and this, with the application of height age curves, allows recognition of three empirical timber site classes. Coniferous commercialism is a code which denotes the possible utilization class, and special codes allow recognition of special conditions, disturbance, or slopes over 45%. Understories are described where seen, and special effort is taken to spot coniferous understories below deciduous growth.

The interpreters are required to make use of as much existing information as possible, coupled with frequent field visits. After interpretation, an Itek copy of the photo is sent to the forestry field staff, who are allotted special funds to ground truth those areas which they consider to be most sensitive for management during the life of the inventory. The field staff work with the interpreters before the maps are made.

Because of time and the specialized interests of this seminar I will skip over the major operations of mapping and the Alberta Forest Inventory Storage and Maintenance Computer System (AFORISM). This summer, AFORISM passed the design stage and is now being programmed. It is due to come on stream in a basic form next spring. This will be closely followed by refined reporting capabilities and the attachment of a management simulator to be known as TIMPLAN.

AFORISM essentially stores stand information and has features which allow the inventory to be kept up-to-date for observed change and for growth. We do not have any immediate plans for a computer graphics system, although a study is being made of the situation. Each stand in AFORISM has a unique identity, so it could act as an attribute file for some future computer graphics system.

The possibility of observing changes in order to maintain the inventory is also under study, but periodic small-scale coverage, such as 1:50 000 photography on a 5-year cycle, is expected to be involved. Significant catastrophic depletions such as fires and windfall are photographed as soon as possible, especially when there are salvage possibilities. Scale, film, and filter appropriate to the job are used. Windfall is the most difficult disturbance to detect by remote sensing, especially when it occurs to dormant foliage and quick results are needed.

AFORISM also requires cover type volume tables in order to estimate stand volumes. This volume table uses representative volume sample plots, and those measurements are harmonized to produce the great detail needed for so many cover types and utilization specifications. Overall bias is eliminated by running the volume table through AFORISM and comparing certain bottom line estimates with statistically objective estimates, then making small adjustments to the volume table.

The Phase 3 project is funded to sample about 1 plot per 6 gross km^2 (2 sq. miles). We are continuing to hire students and measure some ground plots, but these have become so expensive that our expansion budget will be used for large-scale photo (LSP) plots. This technique is now in the early production stage. The cruise compilation system (CRUZCOMP) has been modified to accept LSP plot tallies as well as ground plots, and to handle them together. We take advantage of all other plots we can get our hands on provided they are recent, measured to suitable specifications, and can be located to a Phase 3 stand.

In this paper I have attempted to put into perspective the state of Alberta's timber inventory, with particular reference to the practical application of remote sensing. In my vocabulary, remote sensing includes conventional medium-scale aerial photography which continues to be the workhorse of Canadian forestry inventory and management.

A NEW APPROACH TO FOREST INVENTORY USING REMOTE SENSING

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ABSTRACT

The Inventory Branch of the Ministry of Forests, Province of British Columbia, has developed a new approach for forest inventory using remote sensing. The system is based on a combination of multistage and multiphase sampling. The land is stratified on small-scale (1:20 000) aerial photographs. About 10% of the strata is covered with large-scale (1:200 to 1:1000) 70-mm photographs, and six fixed-radius plots are selected in each stratum for primary samples. A subsample of these strata are also examined on the ground for detailed inventory measurements, and the primary sample estimators are adjusted through double sampling. Secondary sample units are further subsampled in a representative manner for growth, decay, and waste.

The inventory maps are processed by an Interactive Graphics Design System and a Data Management and Retrieval System. Satellite image analysis is used mainly for updating changes and for optimizing the application of supplementary aerial photography.

INTRODUCTION

The 1978 Forest Act in British Columbia requires that an inventory of the land and forests be developed and maintained and that the land be assessed for its potential for growing trees continuously, providing forest-oriented recreation, producing forage for livestock and wildlife, and for accommodating other forest uses. In addition, the Minister of Forests is required to submit to the Lieutenant-Governor in Council an annual report which must include a summary of forest land in the province, showing areas denuded and restocked during the year and the land where productivity was improved.

In order to meet the requirements of the new legislation, the Inventory Branch of the Ministry of Forests has acquired new technology and developed new approaches for conducting forest inventory.

The provincial inventory program prior to 1978 consisted mainly of unit surveys which were implemented on a 10-year cycle. The classification system used during these surveys stratified the land into broad classes such as forest, nonforest, species group, site types, age class, height class, stocking class, etc. Since 1973, the management unit inventory program has been expanded to include the identification of environmental protection areas, including the mapping of sensitive areas in terms of soil and steepness problems, regeneration and plantation constraints, inoperability, avalanche and snow chute problems, high recreational values, and essential habitat for wildlife and fish. In 1977, a more detailed level of inventory was developed which generally covers a watershed or a subunit. An integral part of the subunit inventory system was the development of a new classification and sampling methodology.

CLASSIFICATION AND SAMPLING

The previous inventory program consisted mainly of aerial photo interpretation on 1:15 840 photographs and ground sampling. Each major forest type group was sampled by clusters of two or four fixed-radius plots, and generally up to 16 samples were collected per type group. A major problem with this approach was that some type groups in remote areas were often not sampled and that a cluster of two fixed-radius plots did not always represent its stratum.

The new inventory system is also based on aerial photo interpretation, but homogeneous types are being described in more detail and are sampled with the aid of low-level aerial photo plots through double sampling. The system is generally applied to a management unit area, such as a Sustained Yield Unit (SYU) or Timber Supply Area (TSA). Aerial photographs are pretyped into homogeneous strata prior to the commencement of field sampling. The scale of photography for management unit surveys is 20 000, although in some cases the 1:15 000 scale is accepted as a practical alternative. When highly detailed information is required on any particular part of a management unit such as a watershed (subunit), aerial photographs of 1:10 000 scale are most often used.

Boundaries of homogeneous strata are transferred via kail plotting to base maps. Each stratum or type is given a unique number both on the maps and on the aerial photographs. During the field season, aerial photo interpreters (classifiers) work closely with the field crews to obtain samples of the various strata. Large-scale (1:200 to 1:1000) fixed-base aerial photography is also obtained in a representative manner on approximately 10% of the strata, using twin Hasselblad 70-mm cameras mounted a fixed distance apart on an aerial camera platform attached to a helicopter. In most cases, the photo interpreter is in the helicopter when the 70-mm stereo photos are taken, and implements recorded air calls to aid the species identification. Six fixed-radius plots per type or stratum are located on the large-scale aerial photographs, and these constitute the primary samples.

Measurements on the photo plots include stem count, height and crown diameter by species, and crown closure for the sample. A subsample of the primary samples, generally up to 15 per type group, is visited on the ground for detailed measurements, and this constitutes the secondary sample unit. Each secondary sample consists of six point samples, taken at approximately the same place where the primary samples were obtained. Both the primary and secondary samples are located with the main objective of obtaining a representative sample of the host stratum, rather than establishing tree-to-tree correspondence between them. This modification of multiphase sampling is for optimization of costs primarily, reduction of variance (i.e., obtaining representative samples per stratum at each stage reduces variance), and the optimization of correlation, at an acceptable cost, between the auxiliary variables of primary samples and the primary variables of secondary samples.

Measurements on secondary samples include diameter at breast height, age, height, and pathological indicators for each tree as well as species identification and assessment of crown closure. Depending on the objectives of the inventory, special measurements are often obtained on secondary samples, such as information on soils, environmental conditions, etc. While secondary samples consist mainly of six points located in a straight line across the stratum, where the in-trees are selected with the aid of a relascope, fixed-radius plots are recommended for types in which a large portion of the trees are below the minimum diameter limit. In the case of point samples, the band is selected so that 8 to 12 trees are included in the sample at each point; similarly for fixed-radius plots, the objective is to obtain 50 to 70 trees per sample (total of six plots), and plot sizes are selected accordingly.

Approximately 20% of secondary samples are selected, in a representative manner, as tertiary samples for the assessment of growth and depletion. Permanent growth sample plots are established at the even-numbered points, whereas destructive sampling for decay and waste are obtained at the odd-numbered points.

Based on the data obtained from large-scale aerial photographs (primary samples), field sample plots (secondary and tertiary samples) and ground calls, the 1:20 000 aerial photographs are interpreted in terms of the classification system. The description for each stratum is entered into an attribute file and referenced through the unique numbers. The classification system is applied consistently in a horizontal (stratum) and vertical (layers) plane; hence, a separate description is given for each layer of multistory stands. The principal variables recognized by the classification and sampling systems are forest, range, nonforest, barren, and cultivated land. An especially significant aspect of the new inventory system is the classification of forest land, which is now described in terms of date of establishment, height, crown closure, stocking, history, environmental constraints, and ecological parameters.

COMPUTERIZED MAPPING

The inventory system described above is being implemented simultaneously in each of the six regions in British Columbia during the summer months; hence, a large number of maps must be processed in a short period of time to facilitate the calculation of the required area end descriptive statistics. In addition, the remaining forest type maps must also be updated on a yearly basis in terms of such changes as harvesting, regeneration, and other relevant depletion. Coinciding with these requirements is the need to manage the data base with a flexible retrieval system and to convert the 7,000+ forest cover maps from the imperial to the metric system, including changes in map sheet size from 7'30" by 7'30" (1:15 840 scale) to 12' longitude and 6' latitude (1:20 000 scale).

In order to be able to process the heavy workload within fairly rigid time constraints, the Inventory Branch in 1978 acquired an Interactive Graphics Design System (IGDS) from M & S Computing International Ltd. IGDS is an integrated configuration of hardware and software and features user-controlled graphics combined with data management and retrieval systems. The configuration installed at the Inventory Branch includes the following: two PDP 11/70 computer subsystems operating in a dual-port environment with 256K word memory on each CPU; two 80- and two 300-megabyte disk drives with packs, operating with data scanners; 10 design/digitizer stations, each consisting of two Tektronix screens, a 36 X 48 inch Summagraphics digitizing table with menu and cursor, and a keyboard; a system console and CRT terminals; a tape drive and controller; a Calcomp 960 plotter, a card reader, printer, and two hard copy units; and an interface controller to the IBM 3033 computer.

The software acquired with the system facilitate interactive manipulations and editing of graphic elements and designs, interactive and batch input of map labels containing thematic details, automatic area calculations, and data management and retrieval capabilities. IGDS is capable of storing each design file or map in terms of 63 levels each of which may be retrieved separately or collectively in any combination. Formal overlays of design files can also be created, and areas of original and resultant types and their associated attributes may be obtained in a matter of minutes.

The forest inventory data base currently utilizes approximately 30 IGDS levels, separating such details as aerial photo centers, topography, toponymy, cadastral survey, forest type polygons and their descriptions, etc. Each forest type polygon is associated with an attribute list containing map sheet and polygon number, species composition, age, height, and crown closure, number of stems per hectare, environmental constraints and other relevant descriptive information. The process of digitizing is completely automated by combinations of IGDS and user-developed algorithms integrated to produce maps and reports in accordance with provincial and Forest Service standards. Map labels describing forest types are loaded through the attribute file and placed at the text nodes associated with the unique polygon numbers. The Data Management and Retrieval System (DMRS) software calculates the areas of the close forest type polygons and enters this information into the attribute file. The graphic designs or maps are plotted on mylar in two copies, one for the relevant district and the other for the Inventory Branch. Future changes are then marked on the district's copy, and the design and attribute files are updated on an annual basis thereafter.

Currently two types of manuscripts are being digitized, i.e., the existing 1:15 840 maps with imperial labels and the new 1:20 000 and 1:10 000 series with metric attributes covering the re-inventoried areas. The time required to digitize an average forest cover map consisting of planimetric, cadastral, and thematic details (approximatley 800 polygons) was originally estimated to be 11 to 12 hours of uninterrupted production. Because of staff training and vacancies, it has not been possible to maintain consistently this production goal, although it has been achieved with experienced staff on numerous occasions. The corresponding time to draw a map manually is about 40 hours; hence, there is a substantial increase in throughput by using an Interactive Graphics Design System. IGDS provides the highest benefit-cost ratio during the update stage, when changes can be implemented in terms of minutes, followed by approximately 30 minutes of plotting.

The staffing for IGDS is organized to maximize throughput. Two persons are assigned to each design/digitizer station, and their time is scheduled for continuous operation of the system. Time off the system is spent on preparation, quality control, and other relevant activities.

DATA MANAGEMENT AND UPDATE

The Interactive Graphics Design System has its own data management and retrieval capability, facilitating graphics and attribute file searches, overlays of levels within a file as well as several files, and efficient updates. In addition, the graphics data base is summarized in terms of 100-hectare grids and is being set up on the IBM computer under the MARK IV data management system.

Since recent legislation requires annual updates of forest-type maps and statistics, there are serious operational problems in handling a data base as large as that of the Province of British Columbia. The tool currently used for the update is supplementary aerial photography obtained with the Hasselblad cameras from helicopters. The scale for supplementary photography is generally 1:5000 or 1:10 000, but other variations are often used to meet local objectives. At present, two sets of cameras with platform and related equipment are owned by the British Columbia Forest Service, and an order has been placed to acquire five additional sets. It will be possible, therefore, to decentralize this function by providing one set of cameras to each of six regions. Disturbed areas can then be updated within a short period of time by renting a helicopter, attaching the fully equipped camera platform, and obtaining high-altitude photographs to map the extent of the disturbance. At the same time, low-altitude stereo pairs may also be obtained from the same area to provide a quantitative description of ground conditions such as volume of timber in a residual stand after logging, regeneration, etc.

During the past few years, the Inventory Branch carried out operational trials to test the applicability of satellite image analysis for classification, sampling, and update. The results of these tests indicate that satellite image analysis has great potential for application in forest and range inventory; however, the current state of the art limits a full-scale operational application in British Columbia.

POTENTIAL USE OF A SATELLITE IMAGE ANALYSIS SYSTEM

Specifications for a satellite image analysis system must be defined in terms of both present and future use and in an operational context. The system must be capable of performing operational tasks in the following areas:

1. updates of disturbed areas, e.g., logging, windblow, insect attack, etc.,
2. classification of forest and range lands in accordance with the existing classification system, and
3. monitoring the changes in the data base.

Due to the large volume of data which must be processed at high speed, a satellite image analysis system which the Inventory Branch would consider for acquisition must meet the following broad specifications:

1. capability of classifying images at a high degree of accuracy,
2. capability of processing large volumes of data at high speed (high throughput),

3. capability of "turnkey" operations with existing staff,

4. compatibility with the Inventory Branch's Interactive Graphics Design System, and

5. capability of operating with several terminals.

The IGDS data base contains inventory data in UTM coordinates. These data consist of field and photo samples as well as boundaries and descriptive statistics of each stratum. A satellite image analysis system must be capable of utilizing this information for training and classifying.

USE OF MULTISTAGE SAMPLING
TECHNIQUES IN TIMBER INVENTORY

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MULTISTAGE SAMPLING: WHAT'S IT ALL ABOUT?

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ABSTRACT

Basic ideas of multistage sampling are discussed in nontechnical terms by answering a number of questions which help us to focus on key concepts. What is multistage sampling? When is it useful? How do we use it? How does it relate to other sampling techniques? How do we decide on appropriate sample size and allocation? What shortcomings are associated with it? This paper will outline the essential elements of multistage sampling, illustrate its use with simple examples, and relate it to other common sampling techniques.

INTRODUCTION

In order to obtain information about large and diverse forest areas, foresters are inevitably forced to use sampling to obtain data in a cost-effective way. Statistical methods then are used to summarize the data and estimate resource characteristics. A wide variety of sampling techniques and associated statistical analysis procedures are available, and one of the first questions a forester asks is: What is the best sampling technique to use? The answer to this question depends in part on the objectives of the sample survey. Traditionally these have been stated as 1. minimize cost, subject to precision limits, or 2. maximize precision, subject to cost limits. Cost reflects the resources required to conduct the survey, and precision is usually measured as the variance of the sample estimator. The "best" procedure among several alternatives is the one which most nearly meets the survey objective.

A sampling system is a coordinated set of sampling procedures, measurements techniques, and analysis methods, which selects a sample from the population, makes measurements on the sampling units, and generates estimates of population parameters. Population characteristics limit the scope of feasible alternative sampling procedures, but they are all derived as a combination of sample unit type, stratification method, sample unit selection probability scheme, and subsampling method.

WHAT IS MULTISTAGE SAMPLING?

Subsampling, two-stage sampling, and multistage sampling all refer to a technique which traditionally has referred to sampling within sample units to estimate characteristics rather than measuring the entire sample unit. This presupposes that the sample units are clusters or aggregations of some more basic elements which are of interest.

A simple forestry example implemented by Hasel in 1937 (Schumacher and Chapman 1948) shows that the concept of subsampling has been available for some time. Hasel's objective was to estimate the total timber volume of 9 sections of land stocked with ponderosa pine. The Stage I primary sampling units (PSU) were strips of land 2.5 by 80 chains, with 32 strips for each section for a total of 288 PSU in the 9-section population. The strips were oriented with the long side running east to west across the sections. The Stage I sample consisted of 36 strips selected at random with the restriction that two strips were selected from each half-section (termed blocks by Hasel). Each strip was partitioned into 8 plots or secondary sample units (SSU) 2.5 by 10 chains, and the Stage II sample consisted of 4 plots selected at random within each strip selected at Stage I. Trees were then measured on the entire 2.5 acre plot. Figure 1, taken from Bruce and Schumacher, shows the configuration of the samples. A three-stage sample could have been used if a sample of half-section blocks had been selected instead of sampling within each half-section block. A four-stage sample could have been used if, in addition, a sample of trees was taken in each plot instead of measuring them all.

WHEN IS IT USEFUL?

Subsampling requires sampling units which are clusters of more basic elements of interest, so it becomes potentially useful whenever we are dealing with cluster sample units. Clustering is often useful or necessary when it is difficult or impossible to construct a sampling frame (or population list) from which to sample the objects of ultimate interest. In Hasel's application the objects of ultimate interest were the individual trees, but it was impractical to select a

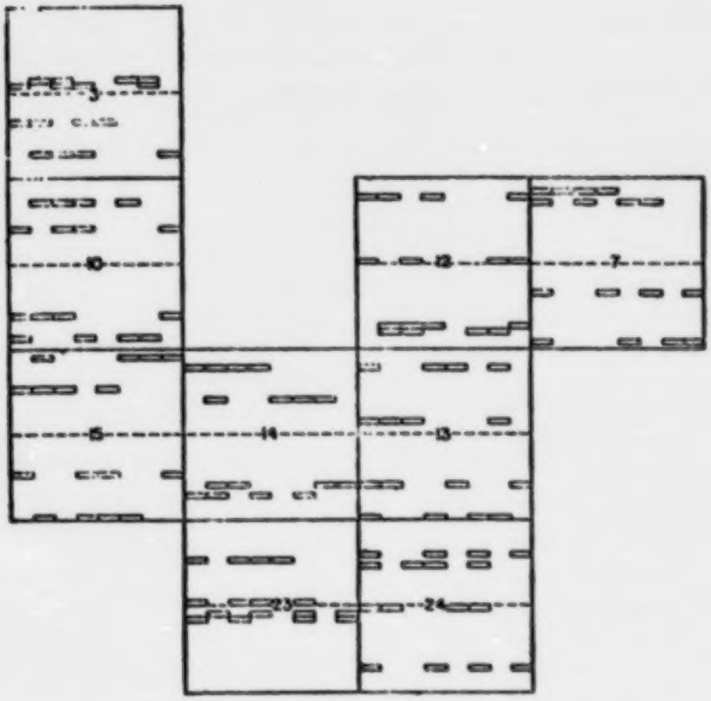

Figure 1. Arrangement of the four SSU (plots) within each of 36 PSU on 18 blocks (half-sections) in a two-stage timber inventory (After Hasel, in Schumacher and Chapman 1948).

random sample of individual trees from the population of all trees. By using fixed areas of land to define the Stage I sample units, it was possible to define a manageable list of sample units from which a sample could be selected. Clustering also offers opportunities for reduction in cost of the survey if travel or access cost is significant.

Clustering alone does not necessarily lead to multistage sampling, but without the first we cannot use the second; size or other characteristics of the cluster sample units often lead to subsampling because it may be impractical or too costly to measure the entire sampling unit. If the cluster is so large that measurement errors become intolerable (at least potentially) then subsampling is useful. Further, if the elements within a cluster are homogeneous, then it is unnecessary to measure all units in the cluster.

Finally, though it is often stated that subsampling does not generally decrease sampling variance (Kendall and Stuart 1968) auxiliary information can be used to improve the sampling efficiency of each stage in the survey. These efficiencies as well as the larger sample size possible as a result of cost savings can often lead to an improved estimate for the same cost if several alternatives are considered.

HOW DO WE USE IT?

Samples are selected at Stage I initially, then a second-stage sample is selected within each PSU selected in the Stage I sample. Stage III samples are taken within units selected at Stage II, and so on. Analysis proceeds in reverse order, beginning with measurements made on the objects of ultimate interest at the last stage. Estimates of sample unit means or totals are made for each sample unit, working backwards until Stage I provides an estimate of the population mean or total. The Appendix shows development of a four-stage estimator for population total and the estimated variance of that estimate. Simple random sampling and equal-size sample units are assumed at each stage, with the same sample size for all subsampling within a given stage. Conventional notation is used to describe the estimator and a corresponding development is included using APL as an alternative notation. The advantage of APL is that it is machine executable, and the resulting estimators can be grouped into six short functions, which will evaluate a multidimensional data array for any number of sampling stages and provide the estimated total and variance. The brevity of this formulation, and its generality, allows the basic structure of the analysis to be seen clearly with a minimum of extraneous detail. Numerical examples for one-, two-, three-, and four-stage sampling, using artificial data, are included using the APL functions.

The examples by Hasel and in the Appendix represent very simple applications of multistage sampling. There are actually few restrictions on the sampling procedures that may be used. If the estimates of PSU means or totals based on subsampling (regardless of the technique or number of sampling stages) are unbiased and the Stage I procedure is unbiased (assuming known PSU totals), then the combined procedure is unbiased. With reasonable sample sizes, biased estimators may be used, especially when bias decreases as sample size increases. This means that auxiliary information of many types can be used to advantage, including such procedures as stratification, variable selection probabilities, and ratio/regression estimators at any stage where it is desirable. It also means that multistage sampling is inherently a general term used to describe an approach to sampling which may lead to a complex combination of many techniques.

Variance estimation is often difficult if we attempt to evaluate it theoretically, since there is variability associated with each new stage of sampling. Sample estimates of variance are easy to obtain, however, if the sampling fraction (ratio of sample size to population size) is small at the first stage (Kendall and Stuart 1968). In that case, the estimate is obtained using the ordinary variance formulas for simple random sampling, as shown in the Appendix. As a consequence of sampling clusters, however, it must be remembered that degrees-of-freedom for confidence intervals must be based only on the number of PSU selected as the Stage I sample.

HOW DOES IT RELATE TO OTHER SAMPLING TECHNIQUES?

Subsampling is a generalization or extension of cluster sampling. Cluster sampling, in turn, is really just a consequence of redefining the population into a more convenient or manageable form. Each cluster sample unit which is subsampled becomes a population of its own, and any valid sampling procedure can be used when subsampling.

Subsampling is often confused with double or two-phase sampling. Double sampling relies on a large sample to estimate a population characteristic for some auxiliary variable, and then takes a small sample to establish the relationship between the auxiliary variable and the primary variable of interest. The smaller sample may be taken independently of the large sample or as a subsample taken from the large sample. This subsample, however, is not a sample within selected units; it is a sample of selected units. Double sampling for stratification is a common example of the large sample being taken to estimate the stratum weights, while the small sample provides the observations within each stratum.

WHAT ABOUT SAMPLE SIZE AND ALLOCATION?

Sample size and allocation depend on costs and variance associated with the different stages of sampling. Defining realistic cost functions and theoretical variance functions is often difficult, but there are results available for many of the more basic multistage designs (Cochran 1977). To make use of them, however, requires more preliminary information about the population that is to be sampled. For this reason it is wise to look for help in addressing this often troublesome aspect of sampling work.

ARE THERE OTHER PROBLEMS WITH MULTISTAGE SAMPLING?

Multistage sampling is often applied to large regional and national populations in order to reduce cost. The major potential difficulty with this approach to sampling is that a small sample of large PSU's may leave many areas of the population unsampled. This does not invalidate the procedures, but it makes it difficult to provide information on subdivisions of the population. If the subdivisions are the same as the PSU, it is usually impossible to make inferences in areas not sampled. For example, if counties or municipal districts are defined as PSU's, then no information is available for counties not sampled. This problem can be avoided if the subpopulations for which estimates are required are known in advance. Unfortunately this issue is often not addressed adequately until after the survey is complete.

CONCLUSION

Multistage sampling has been around for a long time as a specific approach to sampling which can only be used with cluster sample units. It can also provide the framework for more complex systems obtained by combining basic sampling techniques at different stages. The forestry application by Hasel illustrates the basic concept, and analysis procedures outlined in the Appendix show what extensions are necessary with more complex designs.

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APPENDIX

MULTISTAGE SIMPLE RANDOM SAMPLING

USING APL NOTATION:	USING STANDARD NOTATION:
STAGE I: `ETOT←(N1÷SN1)×+/VI`	$ETOT = \frac{N_1}{m_1}\sum_i v_i$

OR:
`ETOT←N1×MEAN VI`
`((ρVI)=SN1)∧(1=ρρVI)`
	$ETOT = N_1\bar{v} \qquad \bar{v} = \frac{1}{m_1}\sum_i v_i$

STAGE II:
`VI←(N2÷SN2)×+/VIJ`
`((ρVIJ)=SN1,SN2)∧(2=ρρVIJ)`
	$v_i = \frac{N_2}{m_2}\sum_j v_{ij}$

STAGE III:
`VIJ←(N3÷SN3)×+/VIJK`
`((ρVIJK)=SN1,SN2,SN3)∧(3=ρρVIJK)`
	$v_{ij} = \frac{N_3}{m_3}\sum_k v_{ijk}$

STAGE IV:
`VIJK←(N4÷SN4)×+/V`
`((ρV)=SN1,SN2,SN3,SN4)∧(4=ρρV)`
	$v_{ijk} = \frac{N_4}{m_4}\sum_l v_{ijkl}$

COMBINING TERMS: `VI←(N2÷SN2)×+/(N3÷SN3)×+/(N4÷SN4)×+/V`	$v_i = \frac{N_2}{m_2}\sum_j \frac{N_3}{m_3}\sum_k \frac{N_4}{m_4}\sum_l v_{ijkl}$

SIMPLIFYING AND GENERALIZING:
`VI←(N2÷SN2)×(N3÷SN3)×(N4÷SN4)X+/+/+/V`
`VI←((N2×N3×N4)÷SN2×SN3×SN4)×+/+/+/V`
`VI←(×/N2,N3,N4)×(+/+/+/V)÷×/SN2,SN3,SN4`
`EPSUTOTS←VI←(×/1↓N)×(PSUSUMS V)÷×/1↓ρV`
	$v_i = \frac{N_2 N_3 N_4}{m_2 m_3 m_4}\sum_j\sum_k\sum_l v_{ijkl}$

SO: `ETOT←(1↑N)×MEAN EPSUTOTS`	$ETOT = \frac{N_1}{m_1}\sum_i v_i = N_1\bar{v}$
AND: `VTOT←((1↑N)*2)×(VAR EPSUTOTS)÷ρEPSUTOTS`	$VTOT = \frac{N_1^2}{m_1(m_1-1)}\sum_i (v_i-\bar{v})^2$

REARRANGING AND COMBINING THESE APL EXPRESSIONS INTO A SET OF 6 FUNCTIONS USING THE DIRECT DEFINITION CONVENTION (SEE ACKNOWLEDGEMENT):

```
ooooooooooooooooooooooooooooooooooooooooooooooooooo
    MSRS:(1↑α) EVTOTAL α EPSUTOTS ω
    EPSUTOTS:(×/1↓α)×(PSUSUMS ω)÷×/1↓ρω:1=ρρω:ω
    PSUSUMS:PSUSUMS +/ω:1=ρρω:ω
    EVTOTAL:α×(MEAN ω),(α÷ρω)×VAR ω
    MEAN:(+/ω)÷ρω
    VAR:(+/(ω−MEAN ω)*2)÷¯1+ρω
ooooooooooooooooooooooooooooooooooooooooooooooooooo
```

EXAMPLES FOLLOW SHOWING USE OF FUNCTION MSRS FOR 1, 2, 3, AND 4 STAGE SAMPLING (USING ARTIFICIAL DATA):

```
      25 MSRS ι10
137.5 572.9166667

      10 20 MSRS 3 5ρι15
1600 333333.3333

      90 10 50 MSRS 3 2 3ρι18
427500 2.43E10

      90 10 50 45 MSRS 3 2 3 4ρι72
73912500 7.8732E14
```

* * *

MSRS RETURNS THE ESTIMATE AND VARIANCE OF THE TOTAL AS A TWO ELEMENT VECTOR. THE LEFT ARGUMENT (α) IS A VECTOR OF POPULATION SIZES FOR EACH STAGE OF SAMPLING. THE RIGHT ARGUMENT (ω) IS A MULTIDIMENSIONAL ARRAY OF OBSERVATIONS FOR EACH STAGE OF SAMPLING. ρω YIELDS THE VECTOR OF SAMPLE SIZES FOR EACH STAGE. ρρω YIELDS THE NUMBER OF STAGES OF SAMPLING. THE EXECUTION OF MSRS MAY BE DESCRIBED AS

1. USING α AND ω AS ARGUMENTS EVALUATE EPSUTOTS (ESTIMATE THE PSU TOTALS).
2. USING THE RESULT FROM 1. AS THE RIGHT ARGUMENT AND (1↑α) AS LEFT ARGUMENT, EVALUATE EVTOTAL (ESTIMATE AND VARIANCE OF THE TOTAL).
3. THE RESULT OF MSRS IS THE RESULT OF EVALUATING EVTOTAL.

EPSUTOTS RETURNS A VECTOR OF ESTIMATED PSU TOTALS. THE ESTIMATE ASSUMES SRS AND EQUAL SAMPLE SIZES WITHIN EACH STAGE. THE LEFT AND RIGHT ARGUMENTS ARE THE SAME AS IN MSRS. IF THE RIGHT ARGUMENT IS A VECTOR (I.E. NO SUBSAMPLING), THEN 1=ρρω AND THE RESULT IS ω. THUS MSRS WILL EVALUATE CORRECTLY FOR A SINGLE STAGE SAMPLE. EPSUTOTS AND THE SUBORDINATE FUNCTION PSUSUMS ARE BASED ON THE ASSUMPTION THAT SUBSAMPLING, REGARDLESS OF STAGE, IS RANDOM AND WITH A CONSTANT SAMPLE SIZE WITHIN EACH STAGE. IF DIFFERENT SUBSAMPLING METHODS ARE USED FOR SECOND AND SUBSEQUENT STAGES THEN THESE TWO FUNCTIONS MUST BE MODIFIED TO REFLECTS THE DIFFERENCES.

PSUSUMS RETURNS A VECTOR CONTAINING THE SUM OF ALL SAMPLE OBSERVATIONS IN EACH PSU. EACH ELEMENT OF THIS VECTOR CORRESPONDS TO A DIFFERENT PSU. IT IS OBTAINED RECURSIVELY FOR ANY NUMBER OF STAGES. THE ω ARGUMENT IS SAME AS THAT FOR MSRS.

EVTOTAL RETURNS THE ESTIMATE AND VARIANCE OF A TOTAL AS A TWO ELEMENT VECTOR. THE LEFT ARGUMENT IS THE POPULATION SIZE (OF PSU IN THE MULTISTAGE CASE) AND THE RIGHT ARGUMENT IS A VECTOR OF SAMPLE OBSERVATIONS (THE ESTIMATES OF PSU TOTALS IN THE MULTISTAGE CASE). THIS FUNCTION WILL EVALUATE CORRECTLY FOR SINGLE STAGE OR MULTISTAGE SAMPLES AS LONG AS 1) THE FIRST STAGE SAMPLES ARE SELECTED AT RANDOM WITH REPLACEMENT OR FROM A LARGE POPULATION, AND 2) THE ESTIMATES OF PSU

TOTALS ARE CONSISTENT WITH THE SUBSAMPLING METHODS ACTUALLY USED. EVTOTAL USES TWO OTHER FUNCTIONS, MEAN AND VARIANCE.

MEAN RETURNS THE MEAN VALUE OF A VECTOR ARGUMENT ω.

VAR RETURNS THE VARIANCE OF A VECTOR ARGUMENT ω.

* * *

ACKNOWLEDGEMENT: DR. K. SMILLIE, DEPARTMENT OF COMPUTER SCIENCE, UNIVERSITY OF ALBERTA, SUGGESTED USE OF THE DIRECT DEFINITION OF FUNCTIONS AND ASSISTED IN FORMULATION OF THE FUNCTIONS.

DIRECT DEFINITION OF FUNCTIONS MAY BE IN TWO FORMS WITH LEFT AND RIGHT ARGUMENTS DENOTED BY α AND ω RESPECTIVELY:

1. FNAME : PRIMARY EXPRESSION

2. FNAME : PRIMARY EXPR : PROPOSITION : SECONDARY EXPR

IN FORM 1. THE RESULT OF EXECUTING THE FUNCTION IS THE EVALUATION OF THE PRIMARY EXPRESSION.
IN FORM 2. THE RESULT IS THE SECONDARY EXPRESSION IF THE PROPOSITION IS TRUE, OTHERWISE THE RESULT IS THE PRIMARY EXPRESSION.

* * *

APPLICATIONS OF MULTISTAGED AND MULTIPHASED TIMBER INVENTORIES

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ABSTRACT

A review is presented of the first Canadian test of multistage sampling with digital classification of LANDSAT imagery, interpretation of small-scale color IR aerial photography, and large-scale photo sampling to estimate softwood timber volumes. This test in the boreal forest region (P6) indicates that there would be a 66% reduction in the variance of the softwood volume estimate when multistage sampling is used instead of random sampling. The approach was applied by Simpson Timber Co. on its lease area in Alberta.

A new project in cooperation with the forest service of the Northwest Territories has more emphasis on a multiphased approach and a hierarchical information system. A test area approximately 2 million ha in size (1 1/2, 1:250 000 map sheets) has been selected. Summer and winter LANDSAT scenes of the test area are being enhanced and digitally classified on the ARIES system in Ottawa for the production of thematic maps. Approximately 500 line miles of color IR at a scale of 1:25 000 were obtained for development of training areas for the LANDSAT classification and evaluation of the thematic maps. The corrected thematic maps, based on the digital classifications of LANDSAT imagery, aerial photography, and field knowledge, will be digitized and each polygon described by a hierarchical coding system. This will provide a data base that may be refined, corrected, and upated with a microcomputer map information system (MIS).

MULTISTAGE SAMPLING

Multistage or multiphase sampling incorporating measures from satellites (LANDSAT), aerial photography, and ground sampling make it possible to obtain forest inventories at reduced cost in a shorter time than is required by random sampling.

The sampling designs are able to take advantage of the overview provided by satellite and/or small-scale aerial photography. The design uses an overview to efficiently locate the sample at subsequent stages. In multistage designs, sample location is related to knowledge gained in the subsequent stage, whereas in multiphase inventories, various scales of imagery and photography are used as required to provide succeedingly more detailed inventories for management, with little or no relationship from one stage to another (Husch 1963, Nichols 1979). As Nichols (1979) states, the two approaches may be combined in various ways in the same survey, and exact naming of the sampling design is difficult.

A test on a multistage sampling design in Alberta was completed on a management unit known as P6. This to date has been the only test in Canada (Kirby and van Eck 1974). An important conclusion reached from the P6 test was that, using digitally classified LANDSAT imagery to indicate the occurrence of merchantable softwood and then applying this information to locate subsequent sampling, it required only one-third the number of samples required by a random approach. This test was on a 3000-km^2 test area. The data used to arrive at this conclusion are presented in the report "A basis for multistage forest inventory in the boreal forest region" and may be used for evaluating various sampling strategies.

The multistage design developed on the P6 test site was applied by the Simpson Timber Company on its lease area in Alberta. Some corrections in the tree volume equations have been made, and a corrected version of "A basis for multistage forest inventory in the boreal forest region" may be obtained by writing the Northern Forest Research Centre in Edmonton.

Recent application of a multiphased design is being completed in the Northwest Territories near Fort Smith.

This project, in cooperation with the forest service of the Northwest Territories, now places more emphasis on a multiphase approach and a hierarchical information system (Legge et al. 1974). A test area approximately 2 million ha in size (1 1/2, 1:250 000 map sheets) has been selected. Summer and winter LANDSAT scenes of the test area are being enhanced and digitally classified on the ARIES system in Ottawa for the production of thematic maps. Approximately 500 line miles of color infrared photography at a scale of 1:25 000 were obtained for development of training areas for LANDSAT classification and evaluation of the thematic maps. The corrected thematic maps, based on the digital classifications of LANDSAT imagery, aerial photography, and field knowledge, are being digitized, and each polygon is being described by a hierarchical coding system. This provides a data base that may be refined, corrected, and updated with a computer map information system (MIS) being developed at the Northern Forest Research Centre.

Estimates of timber volume are being done using a stratified two-stage sampling system with large-scale aerial photographs and paired ground samples on a small proportion of the photo plots.

Currently, the sampling design for multiresource inventories is being studied by Kent, Johnston, and Frayer (1979) and Wensel, Titus, and Thomas (1979). It is interesting to note that in Langley's and Rodas' (1979) most recently published work, they report using a multiphase approach with stand prediction modelling. Thus, multistage and multiphase sampling designs are evolving, and various new approaches are using stratification from satellite imagery and/or aerial photography to reduce sampling costs and time required to complete the inventory.

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A MULTILEVEL APPROACH TO ACQUIRING RESOURCE DATA FOR TIMBER MANAGEMENT PLANNING

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ABSTRACT

A program was developed to provide resource information for industrial management of 5000 km^2 of boreal forest in Alberta. Information needs included areas and yields of broad timber classes for allowable cut modelling, forest cover and volume data retrievable by location for harvest scheduling, and further detailed information for operational planning in priority areas.

False-color infrared photography at 1:50 000 was used for interpreting stand characteristics of the entire area. Second-stage sampling was by large-scale photography. A proportion of the photo plots was measured on the ground. Ground plots were destructively subsampled. Storage and retrieval of inventory data were computerized. Information needs for operational planning are met by superimposing cover type detail on enlarged photomosiacs of priority areas and augmenting the inventory data base by ground and air cruises. Changes occurring between inventories are recorded by a supplementary air photo system.

INTRODUCTION

Simpson Timber Company (Alberta) Ltd., according to the terms of a Forest Management Agreement with the Province of Alberta, is responsible for the development and implementation of forest management plans for 4845 km^2 in the mixedwood and lower foothills sections of the boreal forest. Management planning includes the determination of a sustainable harvest level, the development of feasible harvest schedules recognizing operational and environmental constraints, and short-term planning of logging and silvicultural operations.

Information needs are varied. Long-term planning demands broad area, stocking, and growth data for the whole productive forest land base. This information is incorporated into a resource allocation model (Navon 1971). Harvests of timber classes (aggregated forest cover types) are projected over very long periods of time (20 decades) to determine what optimum cut levels can be maintained without violating public sustained yield policy. Medium-term planning requires data on areas, volumes, and tree sizes for cover types likely to be scheduled for harvesting during the next two decades. These data must be retrievable by location so that inventory reports can be generated for designated planning units. In other respects, however, information for medium-term planning can be fairly broad; stand volumes, for example, are predicted from cover type averages rather than from individual stand assessments. Short-term planning (1 to 3 years) requires a great deal of site-specific information on a relatively small proportion of the total managed area, including detailed stand mapping and assessments of stand condition and operability. Information is also required on volumes and areas actually harvested, relative to those predicted, in order to provide the feedback essential for dynamic planning.

All this information is required within specific time frames. The company was formally required to prepare a detailed long-term management plan within 3 years of start-up. Much of the included inventory information was required earlier. This plan will be revised at intervals of not more than 10 years. The periodic nature of this management planning and associated inventory work can result in uneven demands on technical and professional manpower over time. In spite of this, the company's policy has been to use and develop in-house expertise wherever possible so as to maintain continuity in planning programs and functions. Operating plans and reports are required annually.

Of the total Forest Management Area (FMA), less than 14% will be scheduled for harvest over the next two decades. Approved short-term operating plans, with a 3-year planning horizon, cover 11.6% of the FMA in terms of total land area or 1.2% in terms of areas actually to be harvested. It was this characteristic combination of a small area of high interest with larger areas of lesser interest which prompted managers to review "multilevel" assessment methods, including multistage inventory.

Levels reviewed were satellite imagery, 1:100 000 and 1:50 000 color infrared (CIR) photography, conventional 1:15 000 black-and-white infrared photography, large-scale photography, and ground sampling. Satellite imagery was not used, because the broadest information required on the FMA was more detailed than Level 2 of Anderson's classification (Anderson, Hardy, and Roach 1972). 1:100 000 CIR photography was acquired using a wide-angle lens but was not used extensively because of distortion and vignet problems. 1:50 000 CIR provided satisfactory first-level imagery for stratification of the FMA into forest cover types. Conventional 1:15 000 photography was not flown when it was found that imagery of comparable quality at this scale could be obtained by simply enlarging the CIR. Large-scale photography supplemented by ground plots was used for inventory sampling purposes.

APPLICATION OF COLOR INFRARED PHOTOGRAPHY

CIR (Kodak film 2443) photography at 1:50 000 with minimum forward overlap of 60% was acquired for the whole FMA during the summer leaf-on condition at 7620 m (25,000 feet) above ground level, using an RC-10 camera equipped with a 152-mm lens and antivignet and minus-blue filters. For interpretation of forest cover types, contact-scale continuous transparencies were used. Flight lines were centered between township lines. An entire 93-km^2 township block could be interpreted using one central and two overlapping 23 X 23 cm (9 X 9 inch) frames. The minimum stand size recognized was varied from 20 ha for differentiating similar types to 2 ha or less for nonstocked types within stocked productive forest. Stocked productive forest lands were classified by three crown-density classes, five 6-m height classes, species composition, and age. Disturbance, steep slopes, understories, and other relevant conditions were recorded when apparent. Paper prints were used by the interpreter for air and ground field checking. The age assessments were obtained by defining stand origin boundaries on the photographs and by sequential ground sampling within each area of apparent common origin. Stand areas were measured by electronic planimeter directly from the interpreted photographs. The total estimated stand area for each township was corrected to known township area.

The usefulness of small-scale CIR film in resource evaluation is controversial (e.g., Hegg 1978, Marshall and Meyer 1978). In our experience, this type of imagery had several advantages over conventional films and scales, including synoptic coverage, reduced flying time, and fewer photographs to deal with during data transfer and field checking. For interpretation purposes the tonal information and high resolution of CIR seemed to compensate for the smaller-than-conventional scale. Flying costs per line mile are normally higher at the smaller scale because of the higher leasing costs and shortage of aircraft equipped to operate at the required elevation. Purchase, processing, and printing costs are also higher per unit film area for color than for black-and-white infrared film. On the other hand, coverage of a land area at 1:50 000 needs only 30% as many line miles and 9% as much film as coverage at 1:15 000.

Perhaps the most significant advantage was that the scale and altitude selected facilitated direct area measurement from the photographs with reasonable accuracy. Photo-interpreted data and area measurements were encoded for computer processing without the usual interim mapping stages. This was found to accelerate the planning process and relieve the "front-end" manpower requirement. Photo-analysis production for the FMA averaged 15 km^2 per man-day. This included all phases of interpretation, encoding, field checking, area measurement, and training. A series of ground truth evaluations was made to verify the FMA interpretations. Results are shown in Table 1 for stand height, timber class, and stand age.

Table 1. Field performance of CIR forest cover type interpretation

(a) Stand height

Field type	# of field samples	% of field samples interpreted as:				
		0	1	2	3	4
0 (>6.0 m)	20	60	40	0	0	0
1 (6.1 - 12.0 m)	15	13	74	13	0	0
2 (12.1 - 18.0 m)	11	0	46	36	18	0
3 (18.1 - 24.0 m)	80	0	6	26	67	1
4 (24.1 m +)	14	0	0	21	72	7

(b) Timber class based on species occurence by crown area

Field type	# of field samples	% of field samples interpreted as: 0	1	2	3	4
A Black Spruce-Pine	46	85	9	2	2	2
B Pine	50	12	76	4	8	0
C Pine-Aspen	5	0	20	80	0	0
D White Spruce-Fir	20	5	35	0	55	5
E White Spruce-Fir -Aspen	19	5	5	21	11	58

(c) Stand age

Tolerance interval (years)	Percentage of photo observations: Correct	Incorrect High	Low
± 5	30	34	36
±10	47	27	26
±20	70	12	18
±30	82	8	10
±40	88	5	7

(Based on 141 field observations)

Stand height was important as a basis for stratification of inventory volume samples and as a consideration in operational planning. Heights of stands taller than 6m tended to be underestimated (Table 1a). This bias was fairly consistent, and the interpretation was considered quite satisfactory for stratification purposes. Interpreted heights are adjusted for operational planning.

Timber class (groupings of species based on their occurrence by crown area) and age were the most important interpreted stand variables as regards long-term planning needs. The most serious error in timber class identification resulted from overestimating the proportion of pine in spruce-fir-pine types. A proportion of stands which were predominantly spruce-fir and spruce-fir-aspen were classified as pine and pine-aspen (Table 1b). Although photo estimates of age were frequently incorrect on a stand-by-stand basis, they were quite adequate for broad planning since there was no evidence of interpreter bias (see Table 1c).

In subsequent work undertaken by the company on an additional 12,000 km^2, when expertise was already developed and broader typing specifications were tolerated, productivity was increased to 73 km^2 per man-day.

All characteristics identified during the interpretation and area measurement phases were placed in a stand information file which maintains individual stand identities, is stored on magnetic tape, and can be accessed for revision, retrieval, or further processing. A stand volume table based on subsequent sampling (see below) was used to compute volumes of all stands, but individual stand records can be corrected or updated at any time as in-place information is acquired. A retrieval program enables stand listings and/or inventory summary reports to be generated for any combination of township, range, planning unit, or stand number. Summary reports include a statement of areas and volumes by the timber classes recognized in long-term planning.

SAMPLING METHODS USING LARGE-SCALE PHOTOGRAPHS

While the FMA was being stratified into forest cover types, the softwood growing stock was sampled for volume and other variables. Preliminary estimates of volume by township were based on provisional stand volume tables and typing. Each township block (about 93 km^2) was designated as a primary sampling unit (PSU). A sample of n PSU's (n=9) was drawn with probabilities of selection proportional to the size of the preliminary volume estimates. Each sampled unit provided an estimate of the total volume $\hat{V}$ on the FMA:

$$\hat{V}_i = \frac{y_i}{P_i} = \frac{y_i}{x_i} \times \sum_{i=1}^{N} x_i$$

where: x_i = preliminary estimate of volume on the ith PSU

y_i = volume on the ith PSU (estimated by subsequent sampling)

P_i = selection probability of the ith PSU = $\dfrac{x_i}{\sum_{i=1}^{N} x_i}$

N = total number of PSU's on FMA

As suggested by Cochran (1977) and others, estimates from the n PSU's sampled could be combined to give:

$$\hat{V} = \frac{1}{n} \sum_{i=1}^{n} \frac{y_i}{P_i}$$

for which the estimator of variance $S_{\hat{V}}$ used was:

$$S_{\hat{V}} = \frac{1}{n(n-1)} \sum_{i=1}^{n} \left(\frac{y_i}{P_i} - \hat{V}\right)^2$$

Similarly, each secondary sample unit (SSU) j in the ith PSU provided an estimate of y_i:

$$y_i = \frac{y_{ij}}{x_{ij}} \times \sum_{j=1}^{L} x_{ij}$$

where L = total number of secondary units on the ith PSU, and x_{ij} = preliminary estimate of volume on the jth SSU of the ith PSU.

Only one SSU in each PSU was subsequently sampled. The estimate of FMA volume provided by the ith PSU became:

$$\hat{V}_i = \frac{\frac{y_{ij}}{x_{ij}} \times \sum_{j=1}^{L} x_{ij}}{x_i} \times \sum_{i=1}^{N} x_i$$

$$= \frac{y_{ij}}{x_{ij}} \times \sum_{i=1}^{N} x_i$$

Each SSU was a cluster of n large-scale photo plots (n = approximately 80) occuring on a 10-km flight line. The preliminary estimate of volume x_{ij} on this cluster was computed from provisional stand volume tables. The actual volume y_{ij} was estimated from $\bar{y}_{reg}$, the regression estimate of the corrected mean volume per hectare in the cluster, obtained by double sampling. Thus:

$$\bar{y}_{reg} = \bar{y}_m + b(\bar{x}_n - \bar{x}_m)$$

where:

$\bar{y}_m$ = mean of ground plot volumes Y from a sub-sample on m plots

$\bar{x}_n$ = mean of photo plot volumes X from all n plots

$\bar{x}_m$ = mean of photo plot volumes from the m plots

b = linear regression coefficient

The relationship between photo and ground volumes was expected to be linear (Bonnor and Aldred 1974). Ten percent of the photo plots were included in the subsample for ground measurement. The m plots were allocated to cover types proportionally to volumes predicted by the provisional stand volume tables.

For each flight line, continuous black-and-white coverage at 1:2 600 for ground reference only, and stereo plot color coverage (Kodak film 2445) 1:1 300 were obtained during the "leaf-on" condition by two Vinten 70-mm cameras mounted on a Hiller 12E helicopter. The plot coverage was planned to give 80 samples at systematic 120-m intervals, each sample being of two overlapping photographs. A photo plot consisted of two 20 X 20 m subplots and was centered halfway between the principal points of the two photographs. The following measurements were made on each subplot using a stereoscope, parallax bar, and dot grid: net area, crown area percent (by species), relative crown density (ratio of softwood crown area to total crown area), stand height (average of five trees selected probability proportional to crown area), and stem count (by species).

All trees occurring on ground plots were assessed for species, height, diameter, crown class, and pathological condition, and were subsampled for age. Softwood trees occurring in a systematically selected 25-m^2 quadrant were felled, sectioned, and scaled. Data from the sectioned trees were used to check and correct tree heights by regression estimation, to check the tree volume tables used for predicting total and gross merchantable volume from height and diameter, and to provide net volume conversions for each ground plot tree according to its species and pathological condition.

The uncorrected photo-plot estimates (X) of volume and other variables were predicted from the photogrammetric measurements by regression models. These models were developed by step-wise multiple-regression analysis using all paired photo and ground plot data obtained on the FMA. The independent variables were the stand parameters of height, crown area, density, and stem number and simple transformations of these (Table 2). The most important variable for predicting net stand volumes of all species was crown area times height.

Table 2. Multiple regression results for stand variables

Dependent variable	R^2	Significant independent variables (95% prob.)
Volume (net merch. all swds)	0.79	AxH, H^2, H, Axs
Volume (net merch. pine)	0.92	AxH, DxS, H^2, S, H
Volume (net merch. spruce)	0.74	AxH, A^2, DxS
Swd. stems/ha (total)	0.81	D, DxH, AxH, H^2, H, A, AxS, A^2, DxS
Swd. Stems/ha (merch.)	0.75	HxS, AxH, A, S, A^2
Swd. stems/ha (merch. pine)	0.90	HxS, A, AxH, S, DxS, A^2
Swd. stems/ha (merch. spruce)	0.79	HxS, A, AxS, S, AxH
Basal area (total swds.)	0.58	HxS, A, AxS, AxH
Basal area (merch. swds.)	0.60	HxS, A, AxS, AxH
Diameter (quad. mn. swds.)	0.82	H, H^2, HxS, S, AxS, S^2

A = crown area percent, D = relative crown density, H = stand height, S = stem count.

The softwood inventory design was intended to provide volume estimates at the FMA level $(\hat{V})$ and at the SSU level $(\bar{y}_{reg})$ with sampling standard errors not exceeding ±10 percent. The standard error obtained for the former was 7.6% and for the latter was in the order of 6-7%. (Variance of $\bar{y}_{reg}$ was calculated according to Husch et al. 1972). Corrected plot volume estimates were stratified by cover type and averaged to produce a revised stand volume table compatible with the total FMA volume estimate.

A second inventory was undertaken to assess the FMA hardwood growing stock and its understory stocking levels. A number of modifications were made to the methods used in the softwood inventory. A fixed-wing aircraft (Cessna 206) replaced the helicopter for flying during the spring "leaf-off" condition. A radar altimeter was used, whereas in the previous inventory photo scale was determined from a flying-height profile interpolated from ground checks. Planned photo-plot scale was 1:1 000; plot sizes were reduced to 20 X 20 m. A wide-angle lens was used in the second camera to provide 1:10 000 photography for ground reference. The locations of flight lines in the PSU's, which previously had been arbitrary, were selected with probability proportional to the area of merchantable cover type. Trees for destructive subsampling of the ground plots were selected by prism with probability proportional to size. On the photo plots, instead of measuring several stand parameters, individual measurements were made of height alone on all trees. Estimates of uncorrected photo-plot volume were made using height, diameter, or volume relationships established elsewhere by Kirby and van Eck (1977). These estimates appeared to be low in ground plots containing less than 200 m^3 net volume per hectare.

A correction of photo-plot volumes (X) to ground-plot volumes (y) was obtained by the following regression:

$$Y = 53.5903 + 1.077X - 0.0008X^2$$

with an R^2 of 0.732 (Kirby 1978, personal communication).

At 1977 commercial rates, photography costs were about $4.50 per large-scale photo plot. In the softwood inventory, production for all aspects of preparation and measurement of photo plots was 8.3 plots per man-day, and 0.92 plots per man-day for ground plots. In the hardwood inventory, equivalent production was 6.9 photo plots and 0.21 ground plots per man-day.

PHOTOMAPS FOR OPERATIONAL PLANNING

Based on information from the inventory reports and the allocation model and other considerations, planning units are selected for short-term planning priority. To facilitate operational planning within these units, 1:15 000 forest cover photomaps are produced. These are uncontrolled photomosaics with forest types and other detail superimposed. The steps adopted for producing these maps were as follows:

1. Produce the mosaic using black-and-white prints from the CIR photography enlarged to 1:15 000.

2. Transfer forest typing and other planimetric information from the interpreted CIR photographs to a scribe-film overlay registered on the mosaic, using a zoom transferscope.

3. Produce a final negative and chronaflex transparency of the combined mosaic and overlay using a two-color line system to maintain clarity of the scribed lines.

4. Produce a kodabromide and black- or blue-line prints as required.

Recent costs of producing photomaps averaged $2 per km^2 for mosaicking, processing, printing, etc., plus 0.02 man-days per km^2 for transfer and scribing.

Photomaps have several advantages over conventional line maps in our experience. From the 1:50 000 CIR photography, they provide stand mapping at a level of detail suitable for operational planning without requiring an additional level of medium-scale photography to be flown. They include the benefits of photographic display without the confusion associated with very detailed cover maps. They encourage the user to integrate photo detail and mapped information and do not demand complete reliance on either the photo interpreter and cartographer (as is the case with conventional maps) or the user's own interpretive abilities (as is the case with aerial photographs). They are convenient and easy to use. Data, such as cut-block boundaries, can be plotted on the photomap with greater ease and accuracy than on a line map. They are inexpensive to produce relative to conventional and orthophoto maps. Their potential disadvantages are scale inaccuracies and distortion related to ground or flying height variation and topographic displacement. The extent of this problem was not investigated in detail, but in 2 years of their use no complaints have been received from company or government foresters. The FMA's rolling topography is typical of the lower foothills and mixedwood sections. In steeper areas the use of uncontrolled mosaics would possibly have to be replaced by controlled mosaics or orthophoto maps.

OPERATIONAL CRUISING AND SUPPLEMENTARY AERIAL PHOTOGRAPHY

Once a planning unit has been scheduled for harvesting and has been mapped, further information required for operational planning is obtained. Operational planning involves determining the cutting priority of each merchantable stand according to its current growth, stability, and level of disturbance. Planning also involves consideration of a large number of factors influencing operability and cut-block layout. These factors include: slope, aspect, drainage, soil conditions, regeneration potential, existing roads and other means of access, pipelines and wellsites, and power lines. Some of the required information is provided by the photomap and inventory report already described. The remainder is obtained through a cruise carried out by experienced staff using both helicopter and ground transportation. The basis of this cruise is professional judgment rather than statistical evaluation.

A supplementary air-photo system was developed to meet two main requirements: annual mapping of cutovers and the assessment of disruptive changes (e.g., blowdown, fire) occurring on the FMA between major re-inventories. A leased Cessna 185 was modified to permit the mounting of a 35-mm camera equipped with a standard 50-mm lens, motor drive, interval timber, remote switch, and bulk film chamber. Stereo-overlap vertical photography is obtained at a flying altitude of 8,000 feet (2,438 m) using black-and-white panchromatic or color negative film. This gives a nominal contact scale of 1:48 760 which is enlarged to scales of 1:15 000 or greater. Information is transferred from the printed enlargements to the photomap with the aid of a sketchmaster or transferscope.

DISCUSSION

At the outset of the inventory program, satisfactory stratification of the management area was not available; thus, a stratified sampling design would have meant delaying sampling until cover-type interpretation and measurement were complete (which at the level of detail selected took about 320 man-days). Instead, for volume estimation a multistage design was applied in combination with double sampling. The major disadvantage of this design was that it gave no control over the sampling error within individual cover types. The limiting of sampling efforts to relatively few PSU's was a logistic advantage. Sampling was concentrated in areas of assumed high interest by selecting samples with probabilities proportional to preliminary volume estimates.

CIR photography at 1:15 000 met information requirements successfully in that it provided a suitable basis for broad planning, plus sufficient detail for operational planning.

Measurement of stand parameters from large-scale photography in combination with ground sampling provided satisfactory estimates of average volumes, stem numbers, and diameters for softwoods. Photogrammetic measurements of individual tree heights provided somewhat poorer estimates of hardwood stand variables.

The supplementary aerial photography system along with log scale returns provide information on actual harvests for comparison with scheduled harvests, thus facilitating control of plan implementation.

The management of large, low-productivity forest areas on a sustained-yield basis requires a means of defining priority areas for short-term planning so that forest inventory efforts and other planning inputs can be rationally allocated. Based on our particular experiences, we feel that the logical sequence of inventory and analysis activities for timber management planning in the boreal forest is:

1. broad stratification and sampling of the whole management unit recognizing site, origin, and stocking characteristics and using photography of scale 1:50-000 or smaller,
2. definition of long-term production levels and harvest schedules by incorporating the above data into a suitable allowable-cut model,
3. more detailed inventory to provide species, net volume, dimension, and location information on strata scheduled for harvesting over the next two or three decades,
4. development of feasible cut progressions by operating units to harvest these strata, and
5. detailed stand mapping and operational cruising of units to be operated within the next decade or so.

This requires a flexible means of acquiring different resource data, at different levels of accuracy and detail, for various proportions of the total managed area. This concept does not necessarily involve multistage inventory designs or variable-probability sampling. Indeed, the application of sampling with probability proportional to the size of a single variable is of questionable value in a situation where the manager is always interested in more than one variable. The concept does, however, imply a multilevel approach to aerial photography and inventory methods and reduced emphasis on conventional medium-scale photography and mapping.

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FOREST COVER TYPE CLASSIFICATION FROM LANDSAT DATA ON QUEBEC'S NORTH SHORE

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ABSTRACT

This paper summarizes a 3-year project undertaken in the spring of 1978 to classify forest types over roughly 80,000 square miles (200,000 km^2) on Quebec's north shore in the framework of an ecological land classification preceding hydro-electric installations. An area of 50,000 km^2 is already mapped using five summer LANDSAT images of different dates.

The digital data were first enhanced following a three principal component method using the image enhancement capabilities of ARIES (Applied Resource Image Exploitation System). Color pictures taken from a small aircraft or helicopter were used to correlate the various colors to ground covers, then supervised classifications were performed. Vegetation mapping at a scale of 1:125 000 was also done directly by interpreting the enhancements. The following classes were identified and evaluated as components of a pattern in each unit: dense softwood, open softwood, open lichen-softwood, mixedwoods, hardwood, shrub forested heath, lichen forested heath, shrub heath, lichen heath, open peat land, recent burns.

These results and the problems encountered are discussed. The maps can easily be compared to the synthetic ones produced by Quebec's Department of Lands and Forests using conventional aerial photographs. Cost-benefit estimates are presented.

APPLICATION OF TEMPORAL LANDSAT FOREST DIGITAL DATA TO THE YUKON INFORMATION RETRIEVAL SYSTEM USING ARIES

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ABSTRACT

This paper describes the usefulness of temporal LANDSAT forest digital data as input to Yukon RRAMS, an information retrieval system for renewable resource and management statistics.

The temporal LANDSAT MSS data for a portion of Ecoregion 5 were enhanced to bring out emphasis on (1) softwood, (2) hardwood, and (3) bogs. The usefulness of these enhanced images was evaluated using ground truth data.

The results of unsupervised classification were compared with those of the supervised classification. The results of the supervised classification were geometrically corrected and referenced to the UTM grid cells. Summaries of percentage occupancy in each UTM grid cell by forest land classes are available for direct input into the Yukon RRAMS data base. The forest land classes include softwood, hardwood, regeneration or young growth, shrub land, alpine, water, urban, and others.

TECHNOLOGY TRANSFER

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TRANSFER OF REMOTE SENSING TECHNOLOGY

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ABSTRACT

It is the final step in the fulfillment of the mandate of the Ontario Centre for Remote Sensing to transfer technology and techniques to discipline-specific practitioners in government, education, and the private sector. This paper considers the criteria according to which technology may be selected for transfer and the means by which the transfer of data acquistion and interpretation methodologies could be effectively accomplished. Finally, the paper describes the necessity of developing an operational market for remote sensing services and forecasts how technology transfer will proceed in Ontario.

DEFINITION OF "TECHNOLOGY"

The word "technology" means "know-how" based on advanced hardware. The word is increasingly used to denote techniques that may, but need not, involve sophisticated instrumentation. In this paper, I will equate "remote sensing technology" with "methodologies of remote sensing application" and will briefly describe my own concept of "technology transfer" as I apply it at the Ontario Centre for Remote Sensing.

THE OBJECTIVE OF TECHNOLOGY TRANSFER AT THE ONTARIO CENTRE FOR REMOTE SENSING

The Ontario Centre for Remote Sensing (OCRS) was established 6 years ago by the Ontario government. The purpose of the center is to promote the use of remote sensing in the province by undertaking research, development, and applications projects in response to the data needs of natural resource management and environmental protection. Once a methodology of remote sensing application has been developed, tested, and rendered "operational", the center's role is to transfer that methodology to private industry and interested government personnel in the province. Of particular concern is the transfer to the private sector. The expected result is that the service provided by that methodology will become commercially available and that the private companies offering remote sensing services will become stable and versatile.

THE OCRS WORKING DEFINITION OF "OPERATIONAL"

The question is, at what stage does a methodology become operational and, therefore, ready for transfer?

The Ontario center's response is that a procedure is operational (1) when the problems that would jeopardize the quality of project results are identified and either solved or compensated for and (2) when any difficulties in operational procedures that would tend to make the methodology inefficient are identified and overcome.

This may seem a rather rigorous criterion; however, private industry cannot afford to represent remote sensing methodologies as finalized when they are not. The result would be a disillusioned client, an impoverished company, and a black mark against remote sensing in the minds of persons who might otherwise have been influential in promoting it.

It is not enough, therefore, to formulate a methodology and successfully apply it once. It is necessary to understand why the results are as they are, in order to ensure reliability and consistency. For example, it has been demonstrated amply that thermography can be used to distinguish between the relative warm and cool parts of buildings. Research must still be done, however, to determine what portion or aspect of the thermal signature is due to energy waste and what is inherent in the structure and materials of the buildings, and to evaluate the effect of atmospheric and microclimatic conditions.

I wish to mention two simple examples of several methodologies which are considered operational and transferable by the center: the detection of forest damage by the root rot of red pine (Fomes annosus) using color infrared aerial photography and the evaluation of timber loss by the correlation of a fire boundary visually delineated on LANDSAT with provincial forest inventory records. In each case, the optimum practical imagery has been established, as have the most informative and efficient interpretation method and means of recording and communicating the data.

THE PROCESS OF TRANSFER

Apart from the problem of making methodologies operational, there is also the question of how to transfer them. One of the barriers to technology transfer to private industry is, of course, the financial constraints under which the private sector operates; if a new methodology is not immediately profitable, it may be difficult to find anyone to accept the gift. That attitude is certainly understandable, but short-sighted. To make remote sensing technology transfer possible in a context like Ontario's, private companies must have sufficient vision to take an interest in new methodologies and to take charge of their own informal education in advanced remote sensing.

An important ingredient is proper publicity on the part of the transferor! Even if private companies are willing to seek our new information aggressively, they must first be made aware of the existence and potential benefits of the sources.

Finally, formal remote sensing training on a practical level can foster receptiveness to new methodologies within both government and the private sector. For example, the OCRS gives week-long courses to government professionals at both the practitioner and the managerial levels and has plans to offer similar courses to private industry in the future.

CONCLUSION

The goal of government in Ontario in the transfer of remote sensing research results is to feed a viable remote sensing industry; however, it will only be attained through mutual effort. Once the agency offering a new methodology has publicized it, technology transfer occurs only when the recipient takes it up with a view to formulating imaginative ways of applying it.

THE TRANSFER OF LARGE-SCALE PHOTO TECHNOLOGY IN ALBERTA

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ABSTRACT

The development of large-scale photography as an operational substitute for ground plots in timber cruising is the successful case history described, with emphasis on the problems encountered. Less successful examples and technological gaps are mentioned.

The paper suggests that research and development are inadequate and lack direction, although inventory has fared better than some other forestry specializations. Operational agencies have poor research liaison and do not adequately develop the technical potential of their own staff.

INTRODUCTION

The development and transfer of technology in Canadian foresty leaves much to be desired. Sweeping generalizations are dangerous, and there are some notable exceptions, but considering the importance of forestry in the Canadian economy, the national record is not good. Our research and development budgets (R & D) were a long way below the standard for a developed country even before the latest ill-planned federal cuts. The "Proposition 13" mood in the land is likely to remove as much muscle as fat from the R & D body.

By and large the provinces and industry have not paid their way in basic research or technological development. Some subjects are best handled locally, but 10 autonomous provinces with small populations scattered across this vast country cannot muster the expertise and cooperative brain pool necessary to develop major ideas. They even do not always have the staff capable of monitoring and adopting technological developments elsewhere. The basic researchers just are not there in any appreciable quantity, and neither are the catalytic go-betweens so eloquently described in the theme address.

Each province tends to have the population of a city but the resource inventory problems of a whole country. Alberta's population is something over two million, yet we have a forest estate to manage which compares with the gross area of Japan. Leadership in this matter must come from the federal government. The forest is fundamental to the national economy, environment, and culture. Although the provinces do own most of the forest resource, the federal government derives enormous income from the forest-based sector of the economy.

The development of an operational large-scale photo cruising system by the former Forest Management Institute was a model of what should occur more frequently. A talented and capable team saw clearly a need for a Canadian forest inventory. The R & D and transfer were followed through to the end. Existing technolgy was adopted or was developed where not available. Luckily the team's last gesture was to tailor the procedure to Alberta's situation before self-destructing on All Fool's Eve, 1979.

The irony is that the Forest Management Institute's remarkable talents were directed to forest measurement rather than to forest management. I suppose this was constitutionally a non-controversial subject. Similar things happened in the regional laboratories. The result is that forest measurement techniques have been developed better in Canada than have management techniques. To this audience of forest inventory specialists that is fortunate, but in the wider context it is not. The management situation in Canada is very different from that in the USA and most other countries, and it needs appropriate attention.

In the course of making the inventory generalizations and then moving to the specifics of the case, one must skip over many bright islands in the dark sea. To those other success stories in industry, provincial governments, universities, and especially the regional federal laboratories, I apologise.

TECHNOLOGY TRANSFER

The case which I will examine is the development of the FMI LSP system as applied to the Alberta Forest Service's needs. For the particular circumstances of the current inventory in this province, the system we have works well. Other systems have disadvantages which outweigh the advantages in our situation.

What happened was that at least 20 years ago, and probably longer, several visionaries saw the advantages of measuring trees photogrammetrically on large-scale stereo models rather than sending expensive field crews out to measure and estimate real trees under circumstances which, frankly, often are not conducive to careful and unbiased mensuration. Some of the visionaries were also practical men, and the early writings of people like H. Lyons and C. Kirby record their trials and successes.

The FMI team tackled the problem in a scientific manner and chewed at it piece by piece. They started with sound photogrammetric thinking and solved the problems as they occurred. The following list of terms summarizes the major hurdles:

-Base-height ratio
-Image quality, image motion, and shadow penetration
-Fast cycling camera with acceptable lens
-Measurement of height above the ground
-Control and measurement of tip and tilt
-Species identification
-Regression estimates of volume and dbh from photo parameters
-Digitized stereometers
-Computerized control and analysis
-Usable procedures
-Economic streamlining

It was not until the pieces were in place that the Alberta Forest Service, a busy organization short on time and expertise, could pick up the ball and run. The middle of a game is no place for the players to make a ball, even if they could.

The AFS tried to adopt the technology of the time in the early 1970's, but we ran into problems which we could not overcome. At that time the U.S. military had generated good reconnaisance cameras, and the FMI had used the NRC to develop an accurate foliage penetrating radar altimeter. The AFS lacked suitable image quality, tip and tilt were a problem, and stereo measurement was slow and expensive. The results were encouraging enough to show that this was a viable procedure, but we had to back out and await a more practical package.

The FMI continued cleaning up problems and reached the point where it needed a cooperative agency to help demonstrate the problem. It was an offer we could not refuse. In a joint project the FMI's technology was applied to make an independent estimate of certain statistics in our test management unit P6. Our own work had been based on a small and somewhat subjective sample and required verification of representative volumes using the same map strata. The technique was demonstrated as practical and generally supported our own estimates and those made with somewhat different techniques by Kirby. The results were written up by Aldred, who was kind enough to add my name as coauthor. This is the only reference cited, because it will lead those interested into the preceding bibliography.

It was apparent to the AFS that the technology still had to be tailored to our needs. The FMI saw this and suggested that they could help. This they did, and as you have heard, Aldred was most generously lent to AFS by CFS for 6 months. He did an excellent job of setting the system up for our circumstances. The versatility of electronic control is most impressive when tailored to complement human skills and to cover for human foibles. We now have our own Zeiss Stereocord coupled with a Hewlett-Packard desk top computer, and things are working as Aldred described in his previous paper.

All hardware is now commercially available, so this is another successful transfer of technology in that industry has followed up. The biggest outstanding problem is the airborne equipment. The radar altimeter used has the precision required and works well, but is not yet robust enough for general use

This is a success story of research, development, and technological transfer because one team was capable of all three. It is a sad story, too, because that internationally renowned team has been badly disrupted.

Those who balk at the price of this sophisticated equipment should consider the alternative capital cost of setting up a modern field camp, and they will be pleasantly surprized.

Some speakers have deplored the technological stagnation of the Canadian forest inventory, while others have stressed the changes occurring in these exciting times. I feel that, like the curate's egg, it is good in parts but could be better. Technology is outstripping the abilities of the poor working stiff who is generally prepared to buy and use a good "black box" if it can be plugged into his needs and if he can be assured that it will work. One thing worse than no black box is the wrong black box.

There are three key areas, namely remote sensing, statistical design, and electronic data processing, where good go-betweens are needed to harness existing technology to existing needs. The user organizations also must develop the ability to shop in the technological supermarket, to ignore the flashy wrappers, and to buy what they need or to buy the ingredients and cook what they need.

Some inventory techniques have been widely applied but poorly understood and sadly abused. Point sampling is an example. Horizontal angle gauges are being used with fearful abuse to select trees for tallying and are rarely being used to measure stand basal area. The possibility exists to use vertical angle gauges along a line to measure stand merchantable length, but I am not aware that this simple technological transfer is being attempted.

Sampling design and the statistical theory of estimates are also poorly understood and badly abused. For this poor transfer of technical knowledge I point a finger squarely at the forestry schools. I may be wrong, but I get the impression that the schools of technology are ahead of the universities in giving their students a gut feeling for statistics.

Transportation and communication are success stories, but then the market is wider and the profits greater.

What might have been? Sticking to remote sensing, albeit it a very close range, I can think of some possibilities. What about a portable gizmo capable of looking into a tree to show internal defects? Surely modern holography could do this. Measurements and estimates using a series of terrestrial photo samples challenge my imagination. The photos could be mono or stereo, and one fast-moving photo cruiser putting in occasional detailed conventional plots in a two-phase or multiphase sampling design could bring back an incredible amount of objective sample data.

The size of the resource, problems of access, and increasing labor costs require an investment in technological innovation for timber inventory. I am not satisfied that the agencies concerned are making anything like a large enough investment.

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INVENTORY APPLICATIONS OF RESEARCH AND DEVELOPMENT PROGRAMS

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INTRODUCTION

Simpson Timber Co. (Alberta) Ltd. has been involved in various forest inventory programs ranging from ground sampling, to large- and medium-scale photography, to the use of digital LANDSAT data. These inventory programs can be grouped into three major inventories:

1. the Forest Management Agreement Area (FMA) which is the most complex;
2. the Berland Timber Development Area which is the simplest; and
3. the Deciduous Timber Allocation Area (DTA) which is based on digital Landsat data.

These three inventories will be discussed in terms of development, application of research programs, basic methodology, and the problems encountered in these inventories.

FOREST MANAGEMENT AGREEMENT AREA

In the Forest Management Agreement (FMA) inventory, two research programs were investigated and then applied. The first of these was the use of high-altitude false color infrared photography for the purpose of forest-cover typing. It was decided first that forest-cover typing would be done on black-and-white modified infrared photography at a scale of 1:15 000. After attending the Fourth Alberta Remote Sensing Training Course held in Edmonton, discussions were carried on with various agencies into the use of high-altitude photography as a forest inventory base. These discussions led to the work carried out by the Canadian Forest Service at the Northern Forest Research Centre which involved the experimental use of high-altitude false color infrared (FCIR) photography. Having studied their program and the photography and noting the fact that the cost of this photography would be less than that of the 1:15 000 photography, the decision was made to have our inventory done using 1:50 000 FCIR photography.

The second program investigated was the use of a large-scale photography program for determining stand volumes that would be applied to the 1:50 000 FCIR cover typing. Again, it was the remote sensing training course which drew our interest to this type of program. With the help of the CFS, two large-scale photo inventories, one for softwoods and one for hardwoods, were implemented. In each of the two large-scale photo inventories, ground plots were put in, and through regression analysis of photo-ground plots, volumes were determined. These volumes were developed into volume tables and applied to the 1:50 000 cover typing.

In this FMA inventory program, the results of using high-altitude FCIR photography with large-scale photo-ground sampling has proved to be a valid inventory system. (Dempster and Scott 1979).

BERLAND TIMBER DEVELOPMENT AREA

In the Berland inventory a slightly different approach was used to obtain inventory data. Due to the large area covered and the time factor involved, a broad inventory program was designed. High-altitude FCIR photography at a scale of 1:100-000 was to be flown; however, due to the unavailability of an aircraft to fly at the required altitude, photography was flown at a scale of 1:50 000 using a wide-angle lens.

Cover-type specifications were taken from the FMA inventory and modified so that the minimum productive stand size was increased from 10 ha (20 acres) to 20 ha (40 acres) and the number of species combinations decreased from 920 possible to 16 primary combinations. Cover-type classification codes were developed from the remote sensing legend developed for the Kananaskis area. This legend system was altered slightly to consist of a six-digit number for the classification of forest cover types. Area measurement was contracted out, and the work was carried out at the Northern Forest Research Centre. A computer program developed by C. Kirby of the CFS was altered to compile the data and print the required summaries.

To acquire the volume information needed to determine the AAC, prism plots were located in the major cover types. These volume figures per type were then compared with the FMA volume figures of the corresponding type. As the compared volumes were within ±10% of the FMA figures, the FMA volume tables were used for the calculation of the annual allowable cut (AAC).

This inventory program has indicated that the use of high-altitude photography with broad cover typing and minimum field checking and volume tables from an adjacent area can be a valid inventory system. This inventory, from time of photography to determination of the AAC, was completed in 8 months at a cost of approximately $0.08 per hectare ($0.03 per acre).

DECIDUOUS TIMBER ALLOCATION AREAS

The final inventory at present being investigated is the use of digital LANDSAT data as an inventory base for determining hardwood volumes in the Deciduous Timber Allocation Areas (DTA). Due to the limited access, the scattered location of the various DTA areas, and the fact that other methods were expensive and time consuming, it was decided to investigate the use of digital LANDSAT data. Several discussions were held with various people, and eventually a program was set up with Intera Environmental Consultants Ltd.

The basic procedure of this program is to take a digital LANDSAT image, superimpose the boundaries of the FMA and DTA areas, and through the use of the Image 100 system (Interactive Multispectral Image Analysis System) determine the various forest strata (softwood, hardwood, and mixedwood classified as to merchantable/mature and unmerchantable/immature). Once this is complete, minimum field checking is carried out to determine accuracy of the classifications and use of FMA volume tables to determine the annual allowable cut.

The final step is to compile all data and determine the annual allowable cut.

The FMA area has been classified first because of the excellent ground truth data that was available to choose training areas for the I-100 system and to determine the accuracy of the I-100 system classifications. To date, a supervised classification of softwoods, hardwoods, and mixedwoods has been completed on the FMA. This supervised classification means that the I-100 system was directed to interpret the signature file from a test area which represented a specific cover type; however, any small openings or types smaller than the minimum stand size would also be included. An average accuracy of 71% was obtained by Simpson personnel, while the agency involved obtained an accuracy of just less than 70%. Although these averages are acceptable, it was felt that they could be increased by doing an unsupervised classification. In an unsupervised classification, the I-100 system classifies the various signature files, and the operator must then determine what each classification represents. This is the stage at which this program is now.

The information that has been received to date appears to indicate that this program can predict where the major concentrations of hardwoods, softwoods, and mixedwoods are located.

PROBLEMS

As all of the above inventories use some form of a research program, two basic problems come to light. The first problem is the lack of communication as to what research programs are available and what research programs are being investigated. Because of this, most private industries will use their previous inventory methods instead of more efficient methods and research programs which could greatly improve an inventory. A related problem is the lack of experience in choosing a program and, once chosen, in setting it up for greatest efficiency and operation to meet the particular requirements of a company.

The second major problem encountered is the cost of using highly sophisticated and expensive equipment. Some companies carry out their inventory programs on a 10- or 20-year basis, and purchasing a system may not be cost-efficient. In relation to this is the advancement of remote sensing techniques so that an inventory system purchased now may be obsolete 10 years from now.

SOLUTIONS

The first of these problems has been solved partially by such programs as the Alberta Remote Sensing Training Course, where new techniques are brought forth, and secondly by the consulting firms now coming into existence which can help a company set up a system or determine which system best fits its needs. To completely solve this problem, both research agencies and consulting firms must approach private industry to learn its requirements and provide guidance in the choice and use of available programs.

The second problem can best be solved by developing an inventory system compact enough to be moved to the various users so that they work in their own complex and develop in-house expertise. Any problems which do occur can thus be solved quickly. This system should not only be compact but have the ability to be updated or integrated with newer advanced systems. If this is not applicable, training programs for company personnel should be designed to develop an understanding of the work procedures and equipment used. Trained personnel can thus explain procedures to management personnel and answer their questions without involving the consulting firm.

SUMMARY

Simpson Timber Co. (Alberta) Ltd. has been involved in three inventory programs developed primarily from research programs. Two of these programs, in The Forest Management Agreement Area and the Berland Timber Development Area, involve the use of small-scale FCIR photography coupled with ground sampling as an inventory base for management planning and determination of the annual allowable cut. Both programs have met the requirements for which they were designed. The third program, in the Deciduous Timber Allocation Areas, uses digital LANDSAT data as a base for determining the hardwood annual allowable cut. This project is not yet complete but does appear to indicate that digital LANDSAT data can be used to determine the major concentrations of hardwoods, softwoods, and mixedwoods.

During these inventories, two major problems became apparent:

1. There is a lack of communication as to research programs available and those under development.
2. Highly sophisticated and expensive equipment is required which may not be cost-efficient for inventory programs carried on every 10 or 20 years.

The first problem could best be solved by having research and consulting agencies approach the private sector, determine its needs, and choose which programs may best meet the requirements. The second problem possibly can be solved by developing a compact, cost-efficient system which can be moved from one location to another and be capable of being integrated with newer, advanced systems.

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TECHNOLOGY TRANSFER VIA PROVINCIAL REMOTE SENSING CENTERS

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ABSTRACT

The problem in transferring remote sensing technology from research and development agencies to user agencies and individuals is largely a lack of communication ensuring wide distribution of information. The technology must be practical, current, and readily available throughout the country to users and potential users.

The provincial remote sensing centers within the national program on remote sensing are the key distribution points for the transfer of technology. The Alberta Remote Sensing Center has successfully transferred remote sensing information from research and development agencies to operational agencies.

INTRODUCTION

Before identifying problems that arise in the process of technology transfer from a research and development agency to an operational agency and documenting solutions, clarification of terminology is required. For this presentation, technology has been defined as equipment, techniques, methodology, and information that provides users with a practical means of employing the art or science or remote sensing. A research and development (R & D) agency is any organization or person that has experimentally developed facets of the technology. An operational agency is any agency or individual using remote sensing operationally.

It is also important to identify the type of technology being researched and developed. Is there, to the detriment of the national remote sensing program, too much research and development whose objective is not the practical needs of the users? Is it mainly geared to the future and not the present? Is it theoretical and not practical? Is it geared to the production of equipment that by reason of its cost is beyond the scope of everyone except a few agencies? Research and development is most important, but also important is the fact that technology must be practical, readily available, and of benefit/cost to the majority of users.

CURRENT TECHNOLOGY TRANSFER

The current methods of transferring technology are generally through symposia, courses, workshops, remote sensing publications (seemingly the criteria being the more theoretical and technically involved, the more prestigious), newsletters, brochures, and the old-boy network. These methods reach a limited number of persons: those who venture forth to symposia and courses, purchase publications or proceedings, or have personal contacts. The dissemination of information can be carried out better at a provincial level, closer to the users.

PROVINCIAL CENTERS

The concept of the national remote sensing program included provincial remote sensing centers. These autonomous centers (there are five to date: Nova Scotia, Quebec, Ontario, Manitoba, and Alberta) by reason of their regional location and close proximity to the users have provided a means for the transfer of technology.

ALBERTA CENTER

One of the roles of the Alberta Remote Sensing Center is to facilitate the dissemination of remote sensing information to Albertans and to nearby provinces and the territories. It is carried out by one of the best methods of technology transfer, which is that information and assistance is given to anyone using or wishing to use remote sensing. This necessitates keeping abreast of developments and establishing and maintaining contacts with remote sensing agencies: government, educational institutions, industry, and the private sector in Canada and the United States.

CENTER'S FACILITIES

The Alberta center's technical library and direct terminal link to the Canada Centre for Remote Sensing's (CCRS) Technical Information Service through the CCRS Remote Sensing On-line Retrieval System (RESORS) enables all users to quickly obtain access to more than 20,000 technical documents. These documents include a large number of forestry categories.

The center utilizes another important means of transferring information, education, and training. It sponsors and cosponsors symposia, courses, workshops, and a lecture program throughout the province.

The center, although oriented toward service and not research and development, promotes, initiates, and funds practical remote sensing demonstration projects, including forestry. The results of these projects are available to everyone interested.

CONCLUSION

The Alberta Remote Sensing Center and other provincial centers provide a means of technology transfer from research and development agencies to the most important part of the national remote sensing program---the users.

TRANSFER OF SPACE-AGE TECHNOLOGY TO FOREST INVENTORY IN BRITISH COLUMBIA: PROBLEMS AND SOLUTIONS

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ABSTRACT

During the past two decades, the forest inventory in British Columbia consisted mainly of classification with the aid of conventional vertical aerial photographs and ground sampling. In 1978, the Inventory Branch of the Ministry of Forests, Government of British Columbia, initiated a major upgrading of the inventory system. The technological changes that have been implemented include the refinement of the classification system, the introduction of a multiphase sampling methodology combined with photo mensuration, the acquisition of a computerized mapping and data management system, and the use of satellite image analysis.

The introduction of the new technology created numerous problems, especially in the areas of technical and academic training, implementation of shift work, and general personnel matters.

This paper contains brief discussions of these problems and their immediate and long-term solutions.

TECHNOLOGY TRANSFER

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TECHNOLOGY TRANSFER

Technology transfer is a high priority concern of CCRS. We are at present requesting additional funds to upgrade our receiving stations and analysis facilities to accommodate the LANDSAT-D data to be available in 1981 or 1982. In making this request, we have been able to quote some successes for LANDSAT over the past 7 years, but to some extent we are still saying how wonderful remote sensing is going to be rather than being able to say how wonderful it has been. The adoption of remote sensing technology into operational resource management information systems has not been as fast or as thorough as we originally had hoped or predicted. NASA has had the same experience. In 1977, President Carter's Director of Science and Technology Policy stated that "early optimistic projections of widespread adoption of LANDSAT data application in routine earth resource management and decision-making have not been realized and substantial uncertainties remain about the extent and value of future uses of LANDSAT data."

In Canada the technology transfer process has been only partially successful. Furthermore, the main successes have been in the mapping area rather than in the monitoring area where the real strength of satellite remote sensing lies.

When the LANDSAT remote sensing program was initiated in Canada, the early priority was in the technology -- the receiving stations, data processing, and analyses. This technology has been transferred successfully from the U.S. into Canadian government institutions and industry. Canada has developed an international reputation in ground station technology and in image analysis system development. Although the successes in the hardward field have been impressive, the success in the application of the techniques in operational monitoring situations has lagged.

When the original Cabinet submission was put forward in 1970-71 to authorize participation in the NASA LANDSAT program, it contained a component for the federal funding of remote sensing centers in the provinces, these centers to act as technology transfer agents. Although the concept was originally approved in principle, it was finally turned down; hence we can say that even at that early date the need for special resources to fund the technology transfer process was realized. Despite this set-back, four provinces did manage to establish their own remote sensing centers, and they all have done a credible job of promoting the use of remote sensing in their provinces. There are still six provinces without such centers.

With our original proposal rejected, CCRS was forced to adopt the position that it would be responsible for acquiring, processing, and distributing the data and providing some measure of technical assistance and application development support and that the provincial government agencies would be responsible for developing the techniques and incorporating them into their resource management systems. An application development program with five scientists was established to provide technical assistance to users in Canada.

Technology transfer activities which we were able to undertake within our resources included:

- accepting scientists to CCR on a secondment basis for periods of up to 1 year;
- providing two digital analysis facilities for use by outside agencies. This equipment has been used on many research projects and has contributed to the success of several projects now considered operational, including forest fire fuel mapping and sedimentation mapping in water;
- development of image analysis software which has been transferred to several universities, provincial agencies and industry;
- assistance in training activities. CCRS has no ongoing training activity but does support such activities in provincial centers and universities; and
- working with users to develop applications; few of these have actually reached the true demonstration phase.

To help coordinate the total Canadian remote sensing activity, a Canadian Advisory Committee on Remote Sensing was established with representation from all provinces and from the major disciplines. This committee has largely limited its activities to information transfer and training and has not taken an active role in other aspects of technology transfer.

In summary, the technology transfer process has been slow for the following reasons:

1. The efforts put into the technology transfer activity have not been adequate. An active technology initiative is required.
2. In many resource management problems there has not been a demand for the data. In some cases this lack of interest can be attributed to the fact that the need for better resource management has been developing through public awareness at about the same time as the remote sensing technology.
3. Even in cases where a potential user believes that the technology shows promise and has good prospects of eventually bringing benefits which outweigh the costs, additional manpower and dollar resources are required to run a remote sensing demonstration parallel to the existing operations until its usefulness can be proven. Usually the extra resources

required are not available and the agency concerned is not willing to restrict ongoing operational projects in the hopes of achieving benefits a few years downstream.

4. There is a federal-provincial government mandate problem in that much of the research work is done by the federal government but the resources are managed by the provinces. Better mechanisms for intergovernmental cooperation in the area of remote sensing technology are required.

We come to the conclusion that this technology will not transfer itself. Technology transfer has to be recognized as a legitimate, necessary enterprise which requires concerted effort and resources and in many cases federal-provincial action.

As part of the LANDSAT-D submission, the Department of Energy, Mines and Resources together with the departments of Environment, Agriculture, and IAND have requested resources to set up a technology transfer program. Under this program, federal government departments would be authorized to negotiate cooperative cost sharing agreements with the provinces for the purpose of demonstrating the use of the technology in practical resource management.

If this proposal receives approval, an interdepartmental remote sensing application office would be set up with representatives from the participating departments along with specialists in data analysis. This office would then negotiate agreements with provinces, set up task forces, and carry out demonstration projects according to the wishes of the province concerned.

WORKSHOP ON PRACTICAL APPLICATIONS OF REMOTE SENSING TO TIMBER INVENTORY

September 26 - 28, 1979
Chateau Lacombe, Edmonton

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